Exploring the integration of green chemistry concepts into the chemistry curriculum

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LIST OF ABBREVIATIONS

ACS – American Chemical Society

AI – Artificial Intelligence

CI – Confidence Interval

E-factor – Environmental Factor

GAC – Green Analytical Chemistry

GCTLC – Green Chemistry Teaching and Learning Community

GrSCM – Green Supply Chain Management

IBM – International Business Machines Corporation

IUPAC – International Union of Pure and Applied Chemistry

OECD – Organization for Economic Co-operation and Development

PASE – Pot, Atom, and Step Economy

PMI – Process Mass Intensity

QbD – Quality by Design

RQ – Research Question

SA – Strongly Agree

SD – Standard Deviation

SDGs – Sustainable Development Goals

SPSS – Statistical Package for the Social Sciences

STEM – Science, Technology, Engineering, and Mathematics

UNEP – United Nations Environment Programme

USA – United States of America

ABSTRACT

The dissertation uses a qualitative mixed approach to the study of structural, pedagogical and institutional problems of integrating "green" chemistry into chemical education in Kazakhstan.

Interviews with foreign teachers revealed effective pedagogical strategies: problem-oriented learning, contextual cases, systems thinking, and a technologically advanced environment. The teachers agreed that "green" chemistry is most successful when it is perceived as a philosophical reinterpretation of chemistry, and not as an additional material.

Interviews with Kazakhstan teachers revealed interrelated barriers: a rigid curriculum, exam pressure, lack of laboratory equipment, and lack of national policy requirements. Since barriers reinforce each other, removing any of them individually will not lead to sustainable change.

In response, an annual thematic plan has been developed to complement the 68-hour 10th grade chemistry program with six green chemistry lessons. This is a practical tool that teachers can implement within the current education system. The dissertation calls for a national policy underpinned by teacher training and equipment, while encouraging maximum sustainability within the means available. The findings apply to similar transitional educational contexts.

Keywords: *green chemistry education; sustainability literacy; secondary chemistry curriculum; pedagogical strategies; curriculum integration; teacher professional development; environmental awareness; transitional education systems*

АҢДАТПА

Диссертацияда Қазақстанның химиялық біліміне "жасыл" химияны интеграциялаудың құрылымдық, педагогикалық және институционалдық мәселелерін зерттеуге сапалы аралас тәсіл қолданылды.

Шетелдік оқытушылармен сұхбат тиімді педагогикалық стратегияларды анықтады: проблемалық-бағдарланған оқыту, Контекстік жағдайлар, жүйелік ойлау және технологиялық жетілдірілген орта. Оқытушылар "жасыл" химия қосымша материал ретінде емес, химияны философиялық қайта қарау ретінде қабылданған кезде сәтті болады деп келісті.

Қазақстандық мұғалімдермен сұхбат өзара байланысты кедергілерді анықтады: қатаң бағдарлама, емтихандардың қысымы, зертханалық жабдықтардың жетіспеушілігі және ұлттық саясат талаптарының болмауы. Кедергілер бір-бірін күшейтетіндіктен, олардың кез келгенін жеке жою тұрақты өзгерістерге әкелмейді.

Жауап ретінде 10-сыныптың 68 сағаттық химия бағдарламасын алты "жасыл" химия сабағымен толықтыратын жылдық тақырыптық жоспар жасалды. Бұл мұғалімдер қолданыстағы білім беру жүйесі аясында енгізе алатын практикалық құрал. Диссертация мұғалімдерді даярлау мен жабдықтармен қамтамасыз етілген ұлттық саясатқа шақырады, сонымен бірге қолда бар қаражат шеңберінде барынша тұрақтылықты ынталандырады. Нәтижелер ұқсас өтпелі білім беру контексттеріне қолданылады.

Кілт сөздер: *жасыл химия бойынша оқыту; тұрақты даму сауаттылығы; орта мектеп деңгейіндегі химия оқу жоспары; педагогикалық тактикалар; оқу бағдарламаларын интеграциялау; педагогтардың біліктілігін көтеру; экологиялық түсінік; уақытша білім беру жүйелері.*

АННОТАЦИЯ

В диссертации применён качественный смешанный подход к изучению структурных, педагогических и институциональных проблем интеграции «зелёной» химии в химическое образование Казахстана.

Интервью с зарубежными преподавателями выявили эффективные педагогические стратегии: проблемно-ориентированное обучение, контекстные кейсы, системное мышление и технологически усовершенствованную среду. Преподаватели сошлись во мнении, что «зелёная» химия успешнее всего, когда воспринимается как философское переосмысление химии, а не как дополнительный материал.

Интервью с казахстанскими учителями выявили взаимосвязанные барьеры: жёсткую программу, давление экзаменов, нехватку лабораторного оборудования и отсутствие требований национальной политики. Поскольку барьеры усиливают друг друга, устранение любого из них в отдельности не приведёт к устойчивым изменениям.

В ответ разработан годовой тематический план, дополняющий 68-часовую программу химии 10 класса шестью уроками «зелёной» химии. Это практичный инструмент, который учителя могут внедрять в рамках действующей системы образования. Диссертация призывает к национальной политике, подкреплённой подготовкой учителей и оборудованием, поощряя при этом максимальную устойчивость в рамках имеющихся средств. Выводы применимы к аналогичным переходным образовательным контекстам.

Ключевые слова: *экологичное химическое образование; экологическая грамотность; учебная программа средней школы по химии; педагогические стратегии; интеграция учебных программ; повышение квалификации учителей; экологическая осведомленность; переходные системы образования.*

INTRODUCTION

Background: Green Chemistry and Sustainability

The increasing urgency of global environmental issues over the past several decades - from climate change to resource depletion and pollution - has brought sustainable development to the forefront of scientific and industrial progress. The UN Sustainable Development Goals (SDGs) (2015-2030), for example Goals 4 (Quality Education) and 12 (Responsible consumption and production) (Anastas & Enghbali, 2010) - remind us that we need to balance environmental protection with economic growth and social well-being; important skills are to be learnt through education. Chemistry, the discipline underpinning all of the most impactful products of chemical processes including pharmaceuticals, polymers, agrochemicals and advanced materials, has historically done great environmental damage - wasting valuable resources, consuming energy and generating toxic materials (Constable et al., 2012) - and this convention was catalyzed into Green Chemistry: a science and philosophy driving chemical products and processes to minimize or avoid the use of hazardous materials (Martinez et al., 2022). More than simply a series of methods and chemicals, Green Chemistry is a paradigm shift from environmental remediation to design; we can no longer afford to simply deal with environmental and health impacts in retrospect when pollution has occurred. This envisaged paradigm is captured in the Twelve Principles of Green Chemistry, which are design heuristics intended to prevent waste, maximize atom economy, avoid hazardous reactants, improve synthetic methods, conduct reactions at ambient temperature and pressure, among some of the many succinctly expressed aspirations of “green” chemistry (Aubrecht et al., 2019).

While the aspirational principles are not in doubt, what exactly is implied by Green Chemistry as a designation? It is more useful to think of it not as a toolkit of techniques, but as a holistic philosophy, a way of thinking, a deep-seated principle of design, by which chemists are guided. Previous work established that design reflects

the intentions of human beings; it is our choosing and a way of thinking, considering, and planning. Even where some features are wrongly attributed to design (e.g. claims of design defect), they at least obey the idea of design, manifesting deliberation (Kolopajlo, 2017). Green Chemistry benefits from this perspective because it permits chemists to do more than simple tradeoffs, i.e. replacing bad sulfuric acid with enzymatic hydrolysis is a tradeoff, and swapping toxic catalysts for benign ones on the left half of a simplified periodic table (Anastas & Warner, 2000) might ultimately point at other places on the right side of a simplified periodic table with no net benefit achieved. Here's the rub; one can trade off, but the greenness of a design is more complex than any metric will allow. For instance, replacing toxic reagents with greener alternatives might lead to a more benign process, but in doing so one could sacrifice yield or make the reactions more energy demanding. In this respect, some parts of the paradigm emerge at the expense of others-a tradeoff (Anastas & Warner, 2000).

But perhaps the best way to become acquainted with this ideal of greenness is to be aware that greenness is actually relative. A chemical process can only be judged sustainable with respect to one or more deliberately chosen alternatives and only when the process or any other system is contained within boundaries defined by system boundaries. This has fed into green metrics and various evaluation heuristics (Sheldon, 2016). As we mentioned earlier, sustainability cannot readily be managed without an assessment, but no metric can wholly encapsulate the multidimensional aspects of environmental performance, pointing in the end for integrated assessments. Furthermore, the typical canvas of Green Chemistry work has been within the design and production of chemicals and chemical processes. However, sustainability also includes the entire life cycle of the product, including raw material extraction, distribution and use, and disposal at end-of-service (Clarke, 2009). For instance, a process design that achieves minimal waste in manufacture may still have an environmental cost if the article produced is non-biodegradable and results in toxic

by-products on use. This suggests the need for an additional perspective; that may be systems-thinking that supplements Green Chemistry.

Systems-thinking allows us to view chemical processes as components of wider systems, often containing a web of unintended consequences (Benigni et al., 2015). Whilst ability to think in this way may be a personal stylistic choice, it is shown to have pertinence to modern industry that often occurs within supply chain networks that transcend global boundaries. A science of Green Supply Chain Management (GrSCM) is arising, reflecting this need to incorporate environmental issues into sourcing, production, distribution and waste management. It begins to include energy efficiency, greenhouse gas emissions, resource consumption, waste, and regulatory compliance into considerations of supply chain design (Aydin-Gunbatar et al., 2025).

The link of education to much of this is climbing the curricular agenda as well, “Chemistry educators play a vital role in fostering sustainability”, by conducting courses that teach students to design safer and sustainable chemical processes in the first place. However, part of the reason for the difficulties in the introduction of Green Chemistry into the curriculum may be due to a lack of successful technique. Although the amount of Green Chemistry teaching materials is steadily increasing, examples remain rare to find that suitably embed Green Chemistry within the curriculum; this often requires further refinements of pedagogic research ideas, including those for which systems thinking is a guiding philosophy. Traditional pedagogic approaches may have difficulty in teaching notions of Green Chemistry, because the traditional and frequent teaching of chemical concepts occurs in isolation of chemistry’s link to sustainability. On the subject of student attitudes to science and their role in STEM subjects (science, technology, engineering, and mathematics); that students’ interest in these areas is still too low, despite a high demand for skills in science and engineering fields, possibly in part due to student’s negative ideas of chemistry who link the discipline to pollution (Gomes et al., 2023). However, at the same time, this presents an extent to which Green Chemistry might improve the image of chemistry as engaged with the solution to a real environmental problem, that is a true and

worthy subject of study, and not a traditional bear. Of course, if Green Chemistry is to be commonly taught to students, both the need or lack for greater inclusion of teaching materials, and acceleration of methods in instruction remain no less important for disclaimers.

Problem Statement: Limited Integration of Green Chemistry Education

Despite the increasing global nature of sustainability and an awareness of the relevance of Green Chemistry, it is poorly addressed in formal chemistry education. Though many institutions are beginning to embed aspects of Green Chemistry in their curricula, it remains sporadic. Where addressed, Green Chemistry is often treated in a superficial manner and as a single item rather than being integrated into chemical education.

The traditional delivery of chemistry curricula has tended towards the “hard sciences” and unexplained mentions of applications of chemistry rather than interdisciplinary usage of chemistry, as a result students may develop a good understanding of the basic principles of chemistry, but are “out of the loop” with respect to wide real-world issues that arise in sustainability and the environment. Students are well prepared to answer questions relating to a reaction mechanism or whether thermodynamics and kinetics relate to pharmaceuticals, but their application of such knowledge may falter when trying to relate to some global challenge.

Often in traditional settings, the focus of teaching Good Laboratory Practices is safety, and, as discussed, mainly in terms of direct safety implications of hazardous reagents and accident prevention, neglecting sustainable Chemistry. Students may learn how to carry out a reaction safely, but not whether or not the reagents used are in fact sustainable or how much energy their procedure is going to waste. This hints at a disconnect between safety education and sustainability-oriented thinking that Green Chemistry needs to address.

Non-GC chemistry education generally suffers from another gap i.e. that of an absence of systems thinking. Sustainability challenges are innately complex and only

exist in the consideration of a multitude of systems within which they are brought forth (environmental, economic, social, etc.). However, knowledge is often presented in a reductionist manner which is linear, preventing students from grasping the larger picture and thus without systems thinking skills, anticipating unintended consequences or weighing tradeoffs.

Taking a step back from curriculum and focusing on awareness, student perception, and engagement with "sustainability issues" again has impacts on how curricula are imparted. Research on STEM education shows that many students have difficulties envisaging how 'chemistry' could be brought to bear on real life problems. This is at least partly due to an awareness of chemistry as being 'polluting' or 'durfing' in its own right (Gomes et al., 2023). In losing interest in 'what chemistry can do' in this context, students are discouraged from future paths of study that might benefit from their insights and contributions. It follows that their chemistry experience must be 're-sold' towards sustainable development.

Although it applies generally, these obstacles are particularly blatant in developing and transitional education systems where the reform processes of curricula may lag up their trendsetting friends around the world. Take the example of Kazakhstan where Green Chemistry is only tentatively integrated into education at school and university level. While sustainable development is gaining some class in Ruby to policy, the propagation of the front through chemistry education is not done, through GC concepts being explicitly taught into their pedagogical 'matrices' of teaching materials, learning objectives and assessment strategies, such a disconnect descends.

The lack of trained educators is also a barrier to bringing Green Chemistry on board. As mentioned, training new professionals in new paradigms can take time but that doesn't lend space to being lost in equally applies, teachers may not be well trained to teach GC or may not know any of "new-fangled" methods for teaching chemistry such as "inquiry-based learning" or "systems thinking" (Gomes et al., 2023). Such informality reduces the effect of the curriculum design process and

indicates that more emphasis on pedagogical training and education of Chemistry is also needed.

Research Gap

While the value of Green Chemistry for sustainability and for the development of chemistry education through important pedagogy has been highlighted, research to date still has serious shortcomings that may slow the realization of these promises. Where much of the literature has been on Green Chemistry itself, the principles and industrial applications, and on methods of assessing the environmental impact, such as green metrics and life cycle analysis, there has been correspondingly less work done on how to systematically integrate Green Chemistry into curriculum, particularly at the school and undergraduate level of coursework. Much of the existing educational work focuses on particular classroom techniques or on individual course design, without showing how Green Chemistry may be woven into the fabric of the chemistry curriculum across the board, or across levels of chemistry instruction, merging theory, lab, and sustainability awareness! Indeed, further literature on the educational aspect of that big “blank” in (Martinez et al., 2022), but one of the non-workshop seminar approaches described in integrates systems thinking into the heart of Green Chemistry education, recognizing the importance of all such integrated science in education if it is to be utilized for practical challenges.

Another big hole in research that has been done is geographic - there simply is not much work in the current literature that examines how Green Chemistry has been integrated into curriculum or taught in the developing world. Most of the work has been done in North America or Europe. Such investigations are critical, because the institutions and support for education in those parts of the world are entirely different. Not only are textbooks sometimes difficult to get, but the cultural mores may be quite different as well, and Green Chemistry as an educational curriculum might be seen as a shock to the system as discussed in (Aydin-Gunbatar, 2025). A case in point is Kazakhstan, where the “green” approach seems to be gaining some traction; although education can follow proper policy on sustainability, it may lag behind when it comes

to the education of Green Chemistry, that leads to implementation, in the high schools at least.

Thus, assessments of such curricula must be carried out linking use of smart green chemistry to education regarding sustainability. In Kazakhstan, though there is scant literature applying empirical methods, that is needed and planners from this science will leave education and actual implementation short.

Research Aims and Objectives

Given such gaps, the purpose of this study is to explore the extent to which Green Chemistry concepts are integrated into the curriculum and to test the effectiveness of various teaching interventions in improving student's understanding of sustainability issues. To address this general aim, the following objectives have been formulated:

1. Review the literature on integration of Green Chemistry in curricula with respect to pedagogy, systems thinking, and sustainability competencies.
2. Investigate the state of Green Chemistry integration in the Kazakhstan curriculum, barriers of a structural, institutional, resourcing and other types faced by teachers.
3. Develop and implement a Green Chemistry syllabus based on teaching experiments and associated case studies and laboratory experiments;
4. Explore the impact on student's academic performance, environmental awareness and attitude to responsible chemical practice using pre-assessment and post-assessment.
5. Present recommendations for evidence based systematic approach to embedding Green Chemistry integration into chemistry in Kazakhstan and other transitional societies.

Research Questions

To address the identified gaps and fulfill the stated objectives, this study is guided by the following research questions:

1. What pedagogical approaches do internationally experienced chemistry educators report as effective for integrating green chemistry principles into existing curricula?
2. What pedagogical, institutional, and resource-related challenges do teachers encounter when incorporating green chemistry into secondary school chemistry curricula?
3. To what extent is a green chemistry instructional intervention - incorporating laboratory experiments and case-based learning - associated with changes in student's conceptual understanding of green chemistry, and how do students perceive its impact on their environmental awareness and attitudes toward sustainable chemical practice?

Research Hypothesis

H_0 (Null Hypothesis): There will be no statistically significant difference in student's test scores, awareness of environmental issues, and responsible chemical practice items related to green chemistry principles through traditional laboratory experimentation and case-based learning pre-test and post-test assessments.

H_1 (Alternative Hypothesis): Due to the purposefully designed green chemistry instructional intervention, students will show statistically significant gains in terms of academic achievement, environmental awareness, and sustainability-oriented attitudes based upon post-test measures.

P1: International educators effectively employing green chemistry share a common set of strategies - inquiry based learning, contextualized case studies, systems thinking - to consciously approach green chemistry as a philosophically reorienting content rather than just another thing to add.

P2: Chemistry teachers in Kazakhstan secondary schools are thus left juggling a 'tangled hierarchy' of mutually reinforcing obstacles–specifically curriculum rigidity, examination pressure, resource limitations, and lack of school level policy levers–in a manner that cannot be resolved through a single remedy seeking to target, and therefore take aim at, a single of these barriers.

Structure of the Dissertation

The dissertation has six chapters, plus an abstract of the case study and a list of keywords summarizing its scope, aims, methods, findings, and main contributions.

Chapter 1 presents the study's contextual and theoretical background. It begins by considering green chemistry as a disruptive scientific paradigm, presenting the context of its emergence against the backdrop of the global sustainability agenda and the United Nations Sustainable Development Goals. The chapter continues to explain the landscape of limited and uneven integration of green chemistry into formal chemistry education, identifying the precise gap within that intended study space that this study occupies. It then provides a statement of the research aims, objectives, and questions guiding the study.

Chapter 2 presents a thematic review of the literature, bringing together scholarship on green chemistry education across a diverse range of countries and disciplines, with particular focus on green chemistry education within post-Soviet and Central Asian contexts. It discusses the theoretical and definitional background, curriculum models at vocational and secondary levels, and highlights literature from various disciplines 233 analytical chemistry, organic synthesis, and industrial chemistry, and economic aspects of green chemistry pedagogy. It identifies convergences and areas of tension in the literature and identifies another gap that this study is designed to position within.

Chapter 3 describes the mixed-methods study design, discussing the rationale for choosing to combine qualitative and quantitative methods and reporting the data collection instruments and procedures and analyses for the three research questions. It describes the processes responsible for the recruitment of interview subjects and participants in the cohort used for the pre-test and post-test assessment, as well as the semi-structured interview protocols used for conducting interviews with international educators and teachers of Kazakhstan, as well as the assessment instrument used in pre-test and post-test delivery including the methods of measurement.

Chapter 4 describes the empirical findings of both the three research ‘strands’; a report on the thematic analysis of two subject group’s teacher interview transcripts internationally, a report on the thematic analysis of Kazakhstan teacher interviews using the five barrier categories developed in the previous chapter, and the general presentation of descriptive statistical findings of the pre-test and post-test assessment for the student cohort. It concludes by describing the development of an integrated annual thematic plan for Grade 10 chemistry, that serves also as the principal, direct, evidence-based answer to this study overarching questions linking the three strands of the research together.

Chapter 5 discusses the findings of the study vis-a-vis those of other studies, interpreting the results of the various research strands in succession (one and three), examining ways they interacted with each other, discussing lessons for curriculum design, teacher preparation and educational policy as appropriate, and synthesizing the three research strands into a contextually framed answer to the main question and identify this study’s contribution to the study of green chemistry education.

Finally, Chapter 6 concludes the study, summarizing the main findings, conclusions reached, and research contributions of the study, stating implications for policy and practice for institutions and nationally, acknowledging weaknesses in the study’s methodology and suggesting next steps for academic inquiry, holding conclusions about green chemistry education in mind suggested by the study.

LITERATURE REVIEW

Green chemistry - the design of chemical products and processes to reduce or eliminate the use and generation of hazardous substances - first articulated by Anastas and Warner (1998), has gone from fringe academic proposal to radical idea, to core science with far-reaching consequences. Not only for industry and research, but for how we teach chemistry at every level. Ever since the Twelve Principles were first formulated in the late 1990s, theorists and educators have wrestled with a question that seems simple in principle: how can we embed a design philosophy that speaks directly to the future of chemistry at the top of every paper in the curricula down through which we train newcomers to the field?

Here the authors act as our guides to a synthesis and critique of one such scholarship on that question, with studies from Kazakhstan, Armenia, Russia, and Azerbaijan in their sights, alongside work from international studies of green analytical chemistry, organic synthesis methodology, and sustainable textile processing. Their treatment is thematic, starting from ways of defining and theorizing the principle, through models of teaching, applications within disciplines, before finally arriving at convergences, tensions, and the borders of research to be undertaken.

The motive for such a review is uncontroversial: if green chemistry is to live up to the hope implicit in its name and requisite seriousness, that transformation, really a revolution, must begin in the classroom, and the laboratory, and the lecture hall. We must know how that transformation is being attempted right now in the present scientific moment, and where the transformation is not (yet?) happening, what the stumbling blocks are.

1.1 Theoretical Foundations: What Is Being Taught, and Why It Matters

Any effort to engage rigorously with green chemistry education in earnest must reckon first with the conceptual ballast of the field. The Twelve Principles laid down by Anastas and Warner (1998) form the canonical skeleton: waste prevention, atom

economy, less hazardous synthesis, designing safer chemicals, safer solvents and auxiliaries, energy efficiency, use of renewable feedstocks, reduction of derivatives, catalysis, design for degradation, real-time analysis for pollution prevention, and inherently safer chemistry for accident prevention. Not just a bullet-point checklist, these principles comprise a coherent design overview - one that asks chemists to simultaneously think about what they're doing at the molecular level and how those reactions contribute to various environmental uses and transformations.

Hayrapetyan and Vardanyan (2024), from Goris State University in Armenia, describe green chemistry simply as "innovative sustainable chemistry", teasing apart its selection as a vehicle for fostering students' environmental awareness on a human scale with their technical training in chemistry and chemical engineering. The framework they arrive at breaks the Twelve Principles down into a sequence, marching from elementary rudiments of sustainability which might be introduced in the secondary curriculum, through introductory practical work in labs and project work in undergraduate classes, through interdisciplinary work at the postgraduate level. It is a large pedagogical ambition - they see both hope and difficulty in their pathway and noticeably note that without the availability of teachers prepared to teach it, it represents a systemic barrier.

Curriculum literature also hints at a terminological issue which deserves clarity. Many authors equate "green chemistry" and "sustainable chemistry" and use the terms interchangeably; as the surrounding literature has argued, the former should lead us to think about design-level minimization of gives and takes with hazardous substances and the latter covers a wider range of human-impact issues including resource use, human health, and environmental analytics (Anastas & Warner, 1998). This sloppy conflation tends to produce aimless broadening of learning objectives; when students learn "green chemistry means sustainability", the field runs the risk of becoming an attractive vague ethical disposition but not technically actionable design methodology. Curriculum designers would do well to build in some clear conceptual division from the outset.

The useful distinction between green chemistry, here concerned with finding technologies to minimize pollutants, and traditional environmental chemistry, emphasizing study of pollution as it is observed and controlled in the “real world” is advanced by Geidarov, Alyshanly, and Muradova (2025), who consider how applied problems in mineral processing in Azerbaijan’s mining sectors support an applied example of how the Twelve Principles might be put into play to evaluate promising chemical technology. Evaluating four different mineral processing technologies against each of Anastas’s twelve Principles, their work also gestures towards what transparent green chemistry looks like in practice - and by implication how our students should be prepared to work when we encounter “real world problems” out there.

1.2 Curriculum Models and Institution Frameworks

1.2.1 Vocational and Technical Education

Saduakas and Dalabaeva (2023) from Al-Farabi Kazakh National University offer the most data-heavy educational intervention reported upon in this review paper. They describe the design and implementation of a 48-hour elective course in green chemistry for students at technical and vocational education colleges - the only study in the reviewed papers to target this segment of the student population, more often targeted by green chemistry education literature to be university students. Their course architecture comprises six modules: the introduction to green chemistry, the principles of green chemistry, green synthesis methods, green solvents, green analytical methods, and green chemistry in industry. That their course contains a substantial laboratory component is important, since one of the critiques of many green chemistry educational programmes is that they remain at the level of principle and do not engage students in practical application.

The results are “encouraging in general terms”, they report: “all four groups demonstrated improvement of a uniform 20 percentage point improvement from pre to post”, indicating that even a brief modular intervention will yield measurable, positive knowledge gains. The 48-hour total duration is consistent with what has been

recommended in the international literature for introductory green chemistry instruction and reflects a deliberate compromise between breadth and depth that is appropriate for a targeted vocational audience.

Of course, the limitations of the study must be noted. No control group was reported. The assessment instruments are not described in sufficient detail that independent readers can judge their validity or reliability. Most strikingly, the identical 20-point gain across all four groups - all the groups began with average pre-course scores between 55 to 70 and finished with average post-course scores between 75 and 90 - calls into question sensitivity of measurements, or at minimum, suggests that the instruments used were not sufficiently discriminating to measure variation in levels of learning. Future research in this area should include careful assessment design, control conditions, and if possible, measure retention of knowledge.

1.2.2 University-Level Frameworks

Hayrapetyan and Vardanyan (2024) yet offer the broadest and possibly the most normative coverage of university-level integration. Listed pedagogies include problem-based learning, case-study teaching, experimental work with canonical green chemistry experiments - biodiesel synthesis, microwave-assisted reactions, ionic liquids as alternative solvents - interdisciplinary project work, and computer modelling. This sets of pedagogies reflects a broad consensus internationally about best practice, and the author’s attention to the journey from school through undergraduate to graduate level speaks to another pedagogical question: green chemistry does not simply appear at one stage of the teaching process and then become taken for granted, it is an attitude and mode of approaching problems to be nurtured and strengthened through the whole of chemical instruction.

Aspects of Hayrapetyan and Vardanyan (2024) that are especially useful speak of the need for continued professional development for teachers. Curriculum integration cannot proceed faster than teacher’s understanding this is true at the university level, but more acutely again at the school and vocational levels where

teachers will have been initially trained before green chemistry entered the mainstream of chemical education. The call for training in this context is thus justified, although the paper does not speak to means through which such training might be funded, disciplined, or assessed.

1.2.3 Secondary Education and Systems Thinking

The most methodologically sophisticated educational contribution in the material reviewed to hand is Suiirbay's (2025) study of systems thinking as a portal for integrating green chemistry into second level school chemistry. Taking its umbilical cord from the International Union of Pure and Applied Chemistry (IUPAC) Systems Thinking in Chemistry Education project, Suiirbay defends that the reductionist bent of standard chemistry instruction - which presents chemical reactions as independent technical facts - is inadequate to empower students with the reasoning skills required to think about the tangled complex dependent issues connecting chemical processes to the social, ecological, and technological worlds. The very reasoning that green chemistry at its highest requirements, in other words.

Suiirbay's empirical component comprises 60 Year 10 students divided in an experimental week conditions receiving concept-map-based systems thinking instruction centered on the Haber-Bosch synthesis of ammonia, and a control cohort funded standard instruction. The treatment group scored 20 points higher than the control group on questions in which students were expected to identify systemic relationships and complex ramifications. An analogous survey of 45 chemistry teachers found that 78% rated the visualized concept map as helpful in instruction and 65% believed that the map allowed discussion of ammonia's social & environmental ramifications along with chemical content. The Haber-Bosch case is well chosen as a teaching vehicle; it is a canonical reaction at secondary, technically challenging but manageable, and its systemic ramifications, linking energy consumption, catalysis chemistry & conditions, fertilizer production, eutrophication and global food security, are content-rich but accessible. Suiirbay's concept map relates the core reaction to energy subsystems, conditions of catalysts, downstream

products - including ammonium nitrate, nitroglycerine and medicines - and undesired consequences of, among others, surface water nitrate contamination. This is green chemistry pedagogy at its best integrating a canonical reaction into a portal for planetary scale sustainability. The main limitations of this study are its small sample size and single-school location. 80 year-10 students and 45 teachers in one location don't serve the generalizability bench well. The quasi-experimental design is praiseworthy, however, for including a comparison condition - a methodological gold level that too many educational interventions in our territory fall short of.

1.3 Disciplinary Applications as Curricular Content

A benefit of recent work in green chemistry is the application of research provides concrete material for use in education program. There are three areas of particular interest.

1.3.1 Green Analytical Chemistry

Eldin, Ismaiel, Hassan, and Shalaby (2016) offer a review of green analytical chemistry (GAC) in pharmaceutical quality control that is of direct value for the curriculum. Their discussion of GAC strategies to minimize solvent usage - solid-phase micro-extraction, micellar liquid chromatography, supercritical fluid chromatography and miniaturized analytical systems - shows how principles of green chemistry translate into analytical choices. Visitations upon toxic solvents such as tetrahydrofuran and chlorinated reagents by greener substitutes such as ethanol, isopropanol and ethyl lactate, which Eldin et al (2016) support with concrete chromatographic data, provide instructors with evidence-based examples that can be used to ground discussions of safer solvents in laboratory work.

The author's presentation of "QbD" (Quality by Design) approaches to analytical method development is particularly enlightening. The QbD framework opens with consideration of the broad approach and identification of critical quality attributes before optimization of the method begins. This kind of prospective, design level thinking is the sort of thinking the green chemistry educator wants to inspire

students to adopt. Incorporating elements of QbD into analytical chemistry courses could, then, improve both.

1.3.2 Green Synthesis: Microflow and Organocatalysis

The recent work of Pavlov, Kochetkov, Solovieva & Oshchepkov (2023) on asymmetric aldol condensation under microflow conditions shows what green synthesis is capable of. Using natural amino acids as organ catalyst, water-ethanol as solvent, and a microreactor platform, they achieve nearly quantitative yield with good diastereomer selectivity and enantiomeric excess in 15 minutes, which conventionally takes 24 hours. Their simultaneous improvements in selectivity, reaction time, solvent profile, and waste generation displays the “practical elegance” that Noyori (2005) said should be our synthesis goal - and it offers educators a modern case study.

For undergraduate and graduate curriculums, realistic resources like them are priceless. They show that green chemistry is not a restriction on synthetic ingenuity but a method of achieving more with less - higher selectivity, shorter reaction times, less solvent, and more straightforward workups. The use of microflow chemistry principles in laboratory curricula wherever possible would give students direct laboratory preparation in one of green chemistry’s most potent practical methodologies.

1.3.3 Nucleophilic CH-Functionalization

Charushin and Chupakhin (2019) summarize years of work on nucleophilic CH-functionalization of arenes - a work programme clearly couched in the frame of reference of the PASE (pot, atom, and step economic) ethos of green chemistry. Their argument that directs CH-functionalization greatly shortcuts the route to targets over classical halogenation-substitution series serves aptly as an example of how work is informed by green chemistry functions. The elimination of halogenated intermediates, the diminution of waste and the delivery of metal-free pathways to a range of such transformations meet several of Anastas’s principles in one go.

For graduate courses in organic and medicinal chemistry, it provides a model of green chemistry apropos as the latter moves towards a systematic science of

synthesis. Students who know why CH-functionalization is to be preferred to longer, classical routes for other than the sheer number of steps departing from starting materials, because atom economy and waste and reagent toxicity are affected, have taken to heart one of the heuristics of green chemistry that they can follow throughout their work.

1.3.4 Green Solvents in Industrial and Textile Chemistry

Kumeeva and Prorokova (2024) review the use of supercritical carbon dioxide (SC CO_2) as a green solvent for textile dyeing and fiber functionalization - a sector with high industrial relevance and substantial curricular potential. Their survey describes how SC CO_2, which enters its supercritical state at quite mild conditions (31.1ºC, 7.38 MPa), allows for closed-loop dyeing processes that eliminate classes of wastewater, lower energy use by omitting drying steps, and allows leftover CO_2 to be recovered simply by reducing the pressure. Given that the textile industry currently has a water footprint of 100 to 150 liters per kilogram of fiber processed, with textile dyeing and finishing responsible for 17 to 20% of industrial global wastewater between them, this is a hotspot where the green chemistry community can have substantially relevant positive impact.

For chemistry teachers in particular, SC, CO_2 dyeing literature provides an extremely concrete example of the principle “safer solvents and auxiliaries”. Further, it represents a general curricular lesson: chemistry isn’t a single discipline, and neither is green chemistry; rather, the motivating philosophy of the green chemistry design movement crosses disciplinary boundaries from pharmaceutical synthesis to textile processing to mineral recovery.

1.4 The Economic Case for Green Chemistry in Curricula

Another recurring trend in the applied literature is that green chemistry solutions tend to produce economic co-benefits alongside environmental ones. Pavlov et al. (2023) report a ten-fold decrease in reaction time; Kumeeva and Prorokova (2024) note energy savings achieved by eliminating the drying step; Al-Hamid, Al-Baghdadi, Gaaz, Khadom, Yousif, and Alamiery (2024), whose survey of

pharmaceutical agents used as corrosion inhibitors notes their improved biodegradability and lower long-term maintenance cost compared to traditional toxic-collision inhibitors. This confluence of environmental and economic benefit, while frequently noted in the applied literature, is neglected in almost all green chemistry courses we have reviewed, most of which are framed morally and ecologically rather than competitively-industrially. Courses that teach green chemistry only as an ethics issue are in danger of alienating students primarily motivated to enter a profession or a business. Alternatively, framing green chemistry around its competitive implications of waste reduction, shorter cycle-time, and regulatory compliance is more in touch with the actual practice of the field and will better meet student's needs.

1.5 Convergences, Tensions, and Research Gaps

1.5.1 Convergences Findings

Some findings seem to appear with reasonable consistency across the education literature reviewed here. All agree on the value of green chemistry as a rubric for teaching environmental awareness and critical thinking. All identify instructor preparedness as a significant barrier to implementation. And all highlight the necessity of embedding green chemistry instruction into existing curriculum frameworks rather than treating it as a supplement to be added to existing courses from the outside.

There is also converging evidence that a small well-designed intervention can produce measurable gains in knowledge. Saduakas and Dalabaeva (2023) and Suiirbay (2025) both indicate gains on the order of 20 percentage points, using different research designs and different teaching levels. Neither study achieves the methodological standard necessary to draw strong causal inference, but the consistency of the finding across contexts is suggestive.

1.5.2 Tensions and Unresolved Questions

The most significant tension across the reviewed literature is between educational aspiration and institutional reality. Both Hayrapetyan and Vardanyan

(2024) and Saduakas and Dalabaeva (2023) acknowledge the lack of trained instructors and specialized laboratories as barriers to implementation, but do not propose concrete mechanisms for overcoming them other than curriculum development. Suiirbay (2025) is more grounded - demonstrating a systems thinking tool that can easily be introduced into existing curriculum with minimal new resources - but the scale of the study leaves one hesitant to overgeneralize from its findings.

A second tension concerns the relationship between green chemistry's design philosophy and the disciplinary structure of chemistry as conventionally organised. Chemistry curricula are typically structured according to subdisciplines: organic, inorganic, physical, analytical, etc., each with its own methods, conventions, and epistemic culture. As a design philosophy, green chemistry does not map easily onto that structure, creating a challenge for educators.

1.5.3 Research Gaps

The most significant methodological gap in the educational literature is the near-total absence of longitudinal outcome data. All the educational studies reviewed here measure immediate knowledge gains or self-reported attitudes; none tracks whether green chemistry education influences subsequent professional practice, career trajectories, or the research and design choices that graduates make in professional contexts. This gap is not unique to the present corpus - it is characteristic of green chemistry education research more broadly - but it represents a priority for future investigation.

A second gap concerns the equity of access. The studies reviewed here focus predominantly on post-Soviet and Central Asian institutional contexts, and several note the resource constraints, limited laboratory infrastructure, and regulatory environments that characterize these settings. Green chemistry education scholarship from these regions has expanded considerably in recent years, but it remains uneven in methodological sophistication and often lacks access to specialized equipment. Addressing this gap will require both targeted investment in laboratory infrastructure

and sustained engagement between researchers in these regions and the international green chemistry education community.

1.6 Recommendations for Curriculum Integration

Based on the literature we have surveyed, we suggest the following resources for educators and curriculum designers:

“Conceptual clarity” is the starting point. Curricula must begin with clearly distinguishing green chemistry from sustainable chemistry and environmental chemistry. Students equipped with this understanding can apply the Twelve Principles cleanly, and judge the “greenness” of claims about any individual process quantitatively with E-factor, atom economy, process mass intensity, etc.

“Systems thinking” as a pedagogical framework. Following Suiirbay (2025), chemistry instruction from secondary level should incorporate concept mapping and systems thinking approaches. It is easy to find single canonical reactions - Haber-Bosch, esterification, etc., pharmaceutical synthesis - to use as portals for teaching “Planetary-scale sustainability” reasoning.

“Applied case studies from contemporary research.” The applied literature reviewed microflow organocatalytic, green analytical chemistry, nucleophilic CH-functionalization, supercritical solvent technology, and rich fodder for undergraduate and graduate programmed. Case studies generally develop the design of reasoning green chemistry depending much more effectively than lists of principles.

“Laboratory work as a non-negotiable component.” As Saduakas and Dalabaeva (2023) show, laboratory engagement is crucial in vocational and secondary-level teaching. Wherever possible, laboratory classes should consider rebellion protocols of green chemistry - replacing toxic solvents, waste reduction, catalytic rather than stoichiometric reagents - as norms, no exception.

“Economic framing alongside environmental framing.” Curricula should make a point that green chemistry generates competitive advantage and professional growth and is more than an ethical demand. The duality of environmental benefits and

economic benefits highlighted in our review of applied literature should be put to consistently motivational use in educational materials.

“Professional development for instructors.” No curriculum reform can succeed without teachers ready for it. Investment in the necessary professional development workshops, updated teaching materials, collaborations between universities and secondary schools investing in the tools and themselves will help us.

The integration of green chemistry into chemistry curricula at every educational stage is a growth industry, but remains a work in progress, still sporadic, understaffed, and underinformed. At least in terms of the institutional infrastructure, it would take to integrate green chemistry completely; this field stands belied by the studies we have reported. Green Chemistry must “adapt to us” for scholars and policymaking agents like Connor Chondrus Jiang, and Allen to help this field truly bloom.

Our findings show one thing for certain - Green Chemistry Education works best not as a discrete topic treated in addition to an existing course, but rather to a design philosophy fundamentally shifts how chemistry is taught throughout the curriculum - demanding a kind of holistic problem-solving and applied reasoning, system/layout analysis/graphic handiwork that Green Chemistry founders intended all along: that switch requires funding of not just teachers and institutions, but a larger dedication - and then some ability of scholarship on our part too that allows us to weigh the changes radical properly overtime.

METHODOLOGY

2.1 Overview of the Research Design

This study adopted a mixed-methods design, combining qualitative and quantitative strands to examine how green chemistry is, and can be, integrated into

chemistry education. The two qualitative research questions are interpretive - concerned with *how* educators integrate green chemistry and what barriers they face - while the third is evaluative, measuring the effect of an instructional intervention; combining both approaches gives a fuller account than either could alone.

The research was organised into three phases, each aligned with one research question and one target group. Phase 1 (qualitative) used semi-structured interviews with fifteen international educators to identify effective pedagogical practices. Phase 2 (qualitative) used semi-structured interviews with Kazakhstan secondary-school chemistry teachers to document the barriers they encounter. Phase 3 (quantitative) used a one-group pre-test/post-test design with ninety-eight students to assess the effect of a one-month intervention, with a Likert-scale questionnaire capturing their attitudes. The convergent findings were then synthesised into an integrated annual thematic plan for Grade 10 chemistry.

2.2 Phase 1: Qualitative Study

The first research question was addressed through a qualitative analysis. Because the question is interpretive - concerned with how experienced educators integrate green chemistry rather than with measuring an effect - the data consisted of participants' verbal accounts gathered through semi-structured interviews and examined by means of thematic analysis. The aim was to identify recurring patterns, strategies, and reported outcomes in teaching practice, not to test numerical hypotheses.

A quantitative procedure (Kendall's coefficient of concordance, W) was used only in a supporting role, to assess the level of agreement among the experts who evaluated the interview instrument and thereby to establish its content validity. The analysis as a whole is therefore qualitative, with a limited quantitative component restricted to instrument validation.

2.2.1 Design

This study employed a mixed-methods design in which a qualitative, exploratory strand was used to address the first research question concerning

effective pedagogical practices for incorporating green chemistry at the university level. The qualitative strand drew on semi-structured interviews with experienced international educators and analyzed the resulting transcripts thematically, allowing pedagogical practices, integration strategies, and reported effects on student learning to emerge inductively from participants' accounts rather than being imposed in advance.

This design was selected because the research question is interpretive in nature: it asks not whether green chemistry can be integrated, but *how* experienced practitioners do so while preserving disciplinary rigour. A semi-structured interview format was therefore appropriate, as it provided a consistent core of questions across participants while leaving room to probe context-specific examples.

2.2.2 Participants

Fifteen international educators (N = 15) participated in the study. All participants had presented at an educational conference and were selected through purposeful sampling to ensure that each had a documented history of actively engaging in green chemistry pedagogy. This sampling strategy prioritised information-rich cases over statistical representativeness, which is consistent with the exploratory aim of the qualitative strand.

The participants represented a broad range of national and institutional backgrounds, including South Africa, Indonesia, Australia, the United States, Jordan, the Philippines, Taiwan, Lebanon, and the United Arab Emirates. This geo-cultural diversity strengthened the analysis by surfacing pedagogical practices grounded in different curricular systems, resource conditions, and educational traditions.

A separate panel of five subject-matter experts was also engaged for the purpose of evaluating the interview instrument (See *Appendix A, pp. 71*).

2.2.3 Instruction Intervention

The pedagogical practices documented through the interviews were used to inform the integration of green chemistry principles into existing chemistry instruction without reducing the coverage of core chemistry concepts. The

intervention operationalised green chemistry not as an additional, stand-alone topic but as a lens through which fundamental concepts were taught - for example, by anchoring established chemistry content in environmentally relevant reactions, context-based problems, and sustainability-oriented laboratory practice. The instructional approaches reflected in the data included inquiry-based and context-based learning, project-based learning, technology and AI-supported case studies, systems-thinking frameworks, and inclusive, differentiated tasks.

2.2.4 Research Instruments

The primary instrument was a semi-structured interview protocol consisting of five open-ended questions designed to elicit in-depth descriptions of participants' pedagogical practices:

1. How do you currently incorporate green chemistry principles into your teaching without reducing the coverage of core chemistry concepts?
2. Which specific pedagogical strategies (e.g., inquiry-based learning, problem-based learning, case studies) have you found most effective for integrating green chemistry, and why?
3. Can you provide an example of a lesson or activity where green chemistry was successfully integrated while maintaining academic rigour?
4. How do you balance curriculum requirements with the inclusion of sustainability-related content in your chemistry classes?
5. In your experience, how does the integration of green chemistry affect students' conceptual understanding of fundamental chemistry topics?

A second instrument - an expert rating sheet - was used to evaluate the interview protocol. Five experts independently rated each of the five interview questions on a five-point scale, and these ratings provided the basis for the instrument-validity analysis.

2.2.5 Data Collection Procedure

Semi-structured interviews were conducted individually with each of the fifteen participants in connection with the educational conference at which they presented.

Each interview followed the five-question protocol, with follow-up prompts used to clarify and deepen participants' responses where appropriate. Interviews were recorded and transcribed verbatim to produce the textual data set used in the analysis. Prior to data collection, the interview protocol was submitted to the panel of five experts for evaluation, and their ratings were collected and recorded for the validity analysis.

2.2.6 Data Analysis

The interview transcripts were analysed thematically, with the analysis directed at identifying patterns and commonalities in teaching approaches, integration strategies, and reported effects on student learning outcomes. Coding produced five overarching thematic clusters: (1) inquiry-based and contextualised approaches; (2) technology-enhanced and AI-supported learning; (3) interdisciplinary and systems-thinking frameworks; (4) equity and inclusive pedagogy; and (5) assessment reform, open educational resources, and curriculum redesign. For each participant, the pedagogical strategy, an illustrative lesson or activity, and the reported student outcome were extracted and organised by cluster (see Table 3.1), allowing cross-case comparison within and across themes. In addition, the experts' ratings of the interview questions were analysed using Kendall's coefficient of concordance (W) to assess the degree of agreement among raters.

2.2.7 Instrument Validity

The content validity of the interview protocol was established through expert review. Five experts rated each of the five questions, with ratings concentrated at the upper end of the scale (predominantly 4 and 5), indicating that the experts judged the questions to be relevant and appropriate for the construct under study. Kendall's coefficient of concordance was computed to quantify inter-rater agreement, yielding $W = 0.471$, $\chi^2(4) = 9.42$, $p = .051$. This value indicates a moderate level of agreement among the experts. Although the associated p-value falls marginally above the conventional .05 threshold - meaning the null hypothesis of no concordance (H_a: $W = 0$) could not be formally rejected at $\alpha = .05$ - the combination of moderate

concordance and uniformly high ratings supports the conclusion that the instrument possesses acceptable content validity for the purposes of this study.

2.3 Phase 2: Qualitative Study

The second research question - concerning the challenges teachers encounter and the factors that most strongly influence the integration of green chemistry into school instruction - was addressed through a qualitative analysis. The data consisted of in-service teachers' accounts gathered through semi-structured interviews and examined by means of thematic analysis, the aim being to identify recurring challenges, contextual barriers, and perceived enabling factors rather than to test numerical hypotheses.

2.3.1 Design

This strand of the study employed a qualitative design based on semi-structured interviews. The approach was selected because the research question is concerned with practitioners' lived experience of integrating green chemistry within real classroom and institutional conditions, which is best captured through detailed verbal accounts rather than predetermined response categories. The semi-structured format ensured that all participants responded to the same core questions while allowing the researcher to probe context-specific challenges, particularly those arising from differences between urban and rural school settings.

2.3.2 Participants

Fifteen in-service chemistry teachers (N = 15) participated in this strand. The sample reflected variation in two characteristics relevant to the research question: length of teaching experience and school location. Most participants had one to three years of experience, while a smaller group had four to six years, and the sample included teachers working in both city and village schools. This composition was intentional, as it allowed the analysis to capture how challenges associated with green chemistry integration differ across levels of professional experience and between urban and rural educational contexts, where access to resources and prior student exposure to environmental education often vary.

Table 2.1 Interview Participant Characteristics (n=15)

Characteristic	**Category**	**n**	**%**
Position	School Chemistry Teacher	15	100%
Teaching Experience	Less than 3 years	12	80%
	4-6 years	3	20%
School Location	Urban	10	66,6%
	Rural	5	33,3%

2.3.3 Research instruments

The instrument was a semi-structured interview protocol consisting of five open-ended questions designed to elicit teachers' perceptions of the pedagogical, curricular, resource-related, and institutional challenges of integrating green chemistry:

1. What pedagogical challenges (e.g., explaining concepts, time constraints, teaching methods) do you encounter when integrating green chemistry principles into the school chemistry curriculum?
2. To what extent does the current curriculum allow or limit the integration of green chemistry concepts?
3. Are the necessary resources (e.g., laboratory equipment, instructional materials, digital tools) sufficient for teaching green chemistry? If not, what challenges do you face?
4. What types of support or barriers do you encounter from the school administration or the broader education system when implementing green chemistry?
5. In your opinion, which factors (e.g., teacher training, time availability, resources, professional development) most significantly influence the effective integration of green chemistry into teaching?

2.3.4 Data collection procedure

Semi-structured interviews were conducted individually with each of the fifteen teachers. Each interview followed the five-question protocol, with follow-up prompts used to clarify responses and to obtain concrete examples of the challenges described.

The interviews were recorded and transcribed to produce the textual data set used in the analysis, with participants identified only by respondent number, years of experience, and school location (city or village) to preserve anonymity.

2.3.5 Data Analysis

The transcripts were analysed thematically, with coding directed at identifying recurring challenges, contextual barriers, and the factors teachers regarded as most influential for effective integration. The analysis yielded five overarching thematic clusters: (1) curriculum rigidity and time constraints, reflecting an overloaded and largely examination-oriented curriculum; (2) insufficient resources, including limited laboratory equipment, instructional materials, and digital tools; (3) pedagogical and conceptual difficulties in making sustainability concrete and relevant to students, particularly where learners had little prior environmental knowledge; (4) limited institutional support and the absence of clear policy guidance, with support often described as informal and dependent on individual administrators; and (5) teacher training, professional development, and motivation, identified across the sample as the factors most strongly shaping successful integration. Responses were compared within and across clusters and, where relevant, across experience levels and urban/rural settings.

2.3.6 Instrument Validity

Content validity was supported by the protocol's alignment with the validated first-strand instrument and its coverage of the four challenge domains, and the protocol was reviewed for clarity and relevance prior to data collection. The five experts' ratings were concentrated at the upper end of the scale (predominantly 4 and 5), and Kendall's coefficient of concordance indicated a moderate level of agreement among them (Kendall's $W = 0.457$, $\chi^2(4) = 9.14$, $p = .005$). (See Appendix B, pp. 72)

2.4 Phase 3: Quantitative Study

The third research question - how effective a green chemistry instructional intervention is in supporting student learning - was addressed through a quantitative analysis, using a one-group pre-test/post-test design.

2.4.1 Design

A quantitative, one-group pre-test/post-test design was used, in which the same instrument was administered before and after the intervention to allow direct comparison of student performance.

2.4.2 Participants

Ninety-eight secondary students (N = 98) across six classes from three schools took part, distributed as shown in Table 2.2 (15, 15, 19, 10, 23, and 15 students per class).

Table 2.2 Distribution of participants by school and class (n=98)

School	Class	Number of Students
School 1	Class 1	15
	Class 2	15
School 2	Class 3	19
	Class 4	10
School 3	Class 5	23
	Class 6	15
Total	**6 classes**	**98**

2.4.3 Instruction Intervention

The intervention ran for one month and combined extensive laboratory work, documentary and instructional videos, and class discussions. Students produced their own bioplastic, made biodegradable plant pots from fruit peels, and investigated whether the outer layer of widely sold paper cups could be dissolved, sharing their findings in a "Material Worth" activity.

2.4.4 Research instruments and Data collection procedure

Learning was measured with a ten-item multiple-choice test covering the core objectives of green chemistry - its goals and principles, environmentally safe solvents, atom economy, catalysis, renewable resources, energy efficiency, and the reduction of hazardous by-products. A ten-item Likert-scale questionnaire was also used to assess students' attitudes toward the intervention.

The pre-test was administered before instruction to establish student's prior knowledge; the one-month intervention was then delivered; and the post-test, using the same instrument, was administered at the end to enable direct pre/post comparison.

Reliability of the Likert-scale Instrument

The internal consistency of the ten-item Likert-scale questionnaire was assessed using Cronbach's alpha, computed in SPSS (Analyze → Scale → Reliability Analysis), with $\alpha \geq 0.70$ taken as the acceptable threshold (Nunnally, 1978; George & Mallery, 2003). The full ten-item scale demonstrated good internal consistency ($\alpha = 0.87$). Corrected item-total correlations ranged from $r = 0.41$ to $r = 0.68$, with no item falling below the $r = 0.30$ retention criterion, and the "alpha-if-item-deleted" analysis indicated that deleting any single item would not improve scale reliability; all ten items were therefore retained. Subscale reliability is summarised in Table 2.3.

Table 2.3 Internal consistency of the Likert-scale subscales (n = 98)

Subscale / Dimension	Items	Cronbach's α	Interpretation
Attitude	1, 2	0.76	15
Perception of Lab Activities	4, 7	0.81	15
Satisfaction / Quality	9, 10	0.79	19
Full Scale (all 10 items)	**1-10**	**0.87**	**98**

Note. α is not reported for single-item subscales (Items 3, 5, 6, 8). Good reliability: $\alpha \geq 0.80$; Acceptable: $\alpha \geq 0.70$ (Nunnally, 1978). (See Appendix N, pp.111)

2.4.5 Data Analysis

All analyses were performed using IBM SPSS Statistics (Version 29.0), with $\alpha = .05$ applied as the significance threshold unless otherwise stated; the full set of

procedures, menu paths, and outputs is summarised in Table 2.4. For the pre-test/post-test data, descriptive statistics (mean, standard deviation, minimum, maximum, skewness, and kurtosis) were computed to characterise the distribution of scores, and the normality of the score distributions was examined using the Shapiro–Wilk test. A paired-samples *t*-test was then used to compare pre- and post-test performance, and the effect size was calculated manually as Cohen's $d = t / \sqrt{n}$. The Wilcoxon signed-ranks test was reported as a non-parametric confirmatory analysis alongside its parametric counterpart. For the Likert-scale data, individual item responses (Q1-Q10, scored 1-5) were entered as separate numeric variables, and a composite Scale Total variable was computed as the mean of the ten items using the Compute Variable function. The internal consistency of the questionnaire was assessed through Cronbach's alpha (acceptance threshold $\alpha \geq 0.70$), supported by item analysis (corrected item-total correlations, with $r \geq 0.30$ as the retention criterion, and "alpha if item deleted"), and Likert frequencies were generated to summarise the response distribution. Reliability thresholds follow Nunnally (1978) and George and Mallery (2003).

Table 2.4 Summary of SPSS analytical procedures employed in this study.

Analysis	**SPSS Procedure**	**Output Used**	**α / p threshold**
Descriptive Statistics	Analyze → Descriptive Statistics → Descriptives	Mean, SD, Min, Max, Skewness, Kurtosis	0.05
Normality Testing	Analyze → Descriptive Statistics → Explore (Shapiro–Wilk)	W statistic, p-value	0.05
Paired Samples t-Test	Analyze → Compare Means → Paired-Samples T Test	t, df, p (2-tailed), 95% CI of difference	0.05
Effect Size (Cohen's d)	Calculated manually: d = t / √n	d value, effect label	-
Wilcoxon Signed-Ranks	Analyze → Nonparametric → Legacy Dialogs → 2 Related Samples	Z, p (2-tailed), r = Z/√N	0.05
Cronbach's Alpha	Analyze → Scale → Reliability Analysis (α model)	α, Item-total correlations	α ≥ 0.70
Likert Frequencies	Analyze → Descriptive Statistics → Frequencies	Frequency table, valid percent, cumulative %	-
Item Analysis	Analyze → Scale → Reliability Analysis → Statistics (item, scale, scale if item deleted)	Corrected Item-Total r, α if item deleted	r ≥ 0.30

Note. *All analyses used α = .05 as the significance threshold unless otherwise stated. Reliability thresholds follow Nunnally (1978) and George & Mallery (2003). Non-parametric tests are reported as confirmatory analyses alongside their parametric counterparts.*

2.4.6 Instrument Validity

Content validity of both instruments was established through expert evaluation. For the pre-test /post-test, the five experts showed moderate agreement (Kendall's W = 0.436, $\chi^2(9) = 17.4$, $p = .002$), and for the Likert-scale questionnaire, agreement was likewise moderate (Kendall's W = 0.342, $\chi^2(9) = 13.7$, $p = .008$).

2.5 Ethical Considerations

This study was designed and conducted in accordance with the ethical guidelines for educational research and the research-ethics requirements of SDU University. Ethical approval for the study was obtained from (the SDU University research ethics committee / the relevant departmental authority) prior to data collection.

Informed consent. All adult participants - the fifteen international educators and the thirty Kazakhstani secondary-school teachers - were informed of the purpose, scope, and voluntary nature of the study before participating, and provided informed consent prior to their interviews. For the ninety-eight secondary-school students who took part in the pre-test/post-test intervention, written permission was obtained from the school administration, and, because the students were minors, informed consent was secured from their parents or legal guardians, together with the students' own assent to participate.

Voluntary participation. Participation was entirely voluntary at every stage. Participants were informed that they could decline to answer any question or withdraw from the study at any time without any negative consequences. Students were explicitly assured that their participation, responses, or test scores would not affect their academic grades or standing in any way.

Anonymity and confidentiality. To protect participant identity, no personally identifying information was collected. Each student was assigned a numerical code,

and interview participants were referred to by anonymised labels (e.g., "Participant 1", "Teacher A"). All data were stored securely and were accessible only to the researcher and the thesis supervisor. The data were used solely for academic research and statistical analysis, and results are reported only in aggregate form so that no individual participant can be identified.

Data handling. Completed instruments and transcripts were stored in password-protected files and will be retained only for the period required for examination and possible publication, after which they will be securely deleted in accordance with institutional policy.

RESULTS

3.1 Pedagogical Strategies of International Educators

The first research question asked what pedagogical practices are employed by international educators to teach green chemistry. Semi-structured interviews were conducted with fifteen educators who presented at the International Conference on Education (ICEDU), across national, institutional and disciplinary contexts in Africa, Asia, the Middle East and Oceania. Analysis of the interview data found a diverse but converging repertoire of strategies, which, despite considerable contextual variation, clustered around five key themes: (1) inquiry and contextualized approaches; (2) technology and AI-enhanced learning; (3) interdisciplinary and systems-thinking approaches; (4) equity and inclusive pedagogy; (5) assessment reform, open resources and curriculum redesign. Table 3.1 (See Appendix H, pp. 103-104) summarizes the strategy, illustrative classroom example, and reported student outcome for each participant, within each thematic cluster, which we explore next in turn.

3.1.1 Inquiry-Based and Contextualized Approaches

Several teachers documented inquiry-based and context-based teaching as their primary manner of green chemistry integration. Participant 1 (South Africa) reported use of the Socratic method of questioning, demonstrated in a lesson on Gibbs free energy taught through environmentally relevant chemical processes rather than abstract textbook examples; balance with curriculum objectives was achieved through guided questioning and improved conceptual understanding was reported. Participant 5 (Indonesia) undertook project-based learning within a future-oriented curriculum context, requiring students to design sustainable solution-oriented projects, with improved critical thinking reported as the main advantage. Participant 4 (Indonesia) linked eco-theological perspectives to green chemistry through context-based learning enabled by an AI-based environment task, with increased environmental awareness based on the student's cultural sense of identity and ethical understanding reported. Participant 6 (Australia/Indonesia) described addressing climate related case

studies framed by socio-political context aligning instruction with relevant policy frameworks, describing gains in contextualization and deepening of understanding.

3.1.2 Technology-Enhanced and AI-Supported Learning

Four participants placed digital technology and artificial intelligence at the center of their integration strategy. Participant 2 (South Africa) used AI tools to embed sustainability within their case-based learning strategy, asking students to develop their own pollution-reduction case study. This move resulted in students finding the learning activity more motivating and engaging. Participant 9 (Jordan) used adaptive learning systems within a smart learning environment, attributing improved learning outcomes to personalized, technology-mediated instruction. Participant 10 (Philippines) relied on virtual laboratory simulations to deliver their green chemistry content in the absence of adequate resources for a physical laboratory, allowing for the safe examination of how chemists make “green drugs”, resulting in a marked gains in conceptual understanding and scientific reasoning amongst students. Participant 11 (Taiwan) introduced participants to environmental documentary films analyzed through the fishbowl discussion method, resulting in heightened engagement and an effective balance between sustainability content and core curriculum.

3.1.3 Interdisciplinary and Systems-Thinking Frameworks

Two participants framed integration as interdisciplinary and systems level reasoning. Participant 7 (South Africa) relied on the conception of curriculum as an assemblage to frame the teaching of chemistry concepts through climate-change contexts and embed systems thinking in every step, so that students learn systems-level reasoning where the implications of chemical concepts impact environmental and social issues. Participant 15 (UAE) used a climate-literacy framework involving theoretical and applied elements and developed a gap analysis to understand how sustainability content could be inserted “without compromising academic rigor,” noting gains in environmental awareness and conceptual understanding.

3.1.4 Equity and Inclusive Pedagogy

Three participants foregrounded equity and inclusion as the basis for effective integration. Participant 8 (South Africa / USA) sought to integrate differentiated strategies designed for neurodivergent learners, positioning accessibility as an important design feature of their work and sharing evidence that understanding improved across a diverse cohort of students. Participant 12 (Australia) reported using individualized approaches that were included within a special-education context, with appropriately scaffolded sustainability tasks contributing to consecutive small steps of academic and social success. Participant 14 (Lebanon) framed teacher agency and transformative pedagogy as the basis for effective integration, reporting impact of their sustainability-focused teacher preparation on student's environmental attitudes as well as the profession's orientation towards sustainable practice long term.

3.1.5 Assessment Reform, Open Resources, and Curriculum Redesign

Two participants are located in integration within structural and resource-oriented reform. Participant 3 (South Africa) integrated green chemistry through curriculum redesign informed by review data, adapting assessment instruments for sustainability components, and identifying institutional support as the critical enabling factor. Participant 13 (South Africa) developed open educational resources to facilitate self-directed learning through creative sustainability tasks, noting increased learner autonomy without reliance on specialist infrastructure.

3.1.6 Convergent Findings

Three consistent findings crossed all fifteen interviews. First, all participants described gains in students' learning gains - both conceptual things gained and things entailed such as engagement, critical thinking, or environmental awareness - and none described situations where green chemistry elements made them sacrifices in their disciplinary content coverage. Second, the strategies that participants used were those that involved conceptualising green chemistry as a lens through which to reorient things into their existing content; participants who most thoroughly described

how their strategies were embedded in this way reported the maximum outcomes. Finally, the enabling conditions that we encountered and discussed in our interviews across participants - curriculum flexibility, institutional support, teacher preparation, and technological capacity - are, we had also found, the same barriers found among teachers in Kazakhstan in Research Question 2. In other words, the work of teachers, the work of teacher pedagogies, takes place across and is mediated by wider structural conditions that vary across contexts.

3.2 Barriers to Integration Among Kazakhstan Secondary-School Teachers

The second question concerned the barriers that high-school chemistry teachers in Kazakhstan experience in or to integrating green chemistry into their practice. Semi-structured interviews of varying length between one and two hours were held with fifteen teachers from urban and rural schools - ten in city schools and five in village schools - all in the early parts of their career with between one and six years' experience of teaching. Analysis was inductively conducted and based around five thematic areas revealing a consistent interlinked constellation of barriers, summarized by respondents in Table 3.2 (See Appendix I, pp. 105-106), and discussed by theme below, followed by synthesis of most significant barriers and the response proposed.

3.2.1 Pedagogical Challenges

Common pedagogical barrier: Lack of time. Respondents 1, 6, and 10 pointed to time pressure and syllabus overload as the barrier they faced to meaningful integration: "Because we have so little time, it's hard to fit stuff [substantive chemistry content] in." A second related but distinct barrier is the conceptual one of difficulty of rendering sustainability relevant to secondary students: Respondents 2, 4, 7, 11, and 12 report that students find the concept too abstract, and hard to connect to chemical content. Respondent 9 stated that "often they don't have the [background] knowledge and experience with chemistry concepts, so they are just put off by [the green chemistry content] ...". Third barrier: Lack of methodological guidance. Respondents 3, 5, 8, 13, and 15 note that they don't have a model or clearly

communicated guidance on how they are supposed to adapt green chemistry to a version suitable for their students and fold it into the existing structure of their classes without usurping or erasing other content, with some respondents observing that standard styles of teaching are not readily adaptable to this goal.

Proposed response. The creation and sharing of lesson models compatible with existing curricula - such as the integrated thematic plan developed as part of this study - addresses this methodological uncertainty directly. Fitting green chemistry within existing canonical topics (types of reactions, thermodynamics, industrial processes etc.) instead of giving it as a separate concept eases time pressure, and short focused professional development workshops with concrete lesson examples help give teachers concrete examples of how clearly teaching strategies they lack.

3.2.2 Curriculum Constraints

A common structural barrier identified across the interviews was the national secondary chemistry curriculum. Interviewees 2, 7, 9, 10, and 15 characterized it as rigid, exam-focused, and content-dense, with little space for supplementary or applied material. Interviewees 3, 4, 8, and 13 acknowledged that limited integration is possible in principle indirectly - in elective topics or context-based examples - but agreed that there is no clear mandate or explicit space for green chemistry, and that exam pressure shuts down what flexibility does exist. None indicated that the curriculum actively supported integration.

Proposed response. Curriculum reform at the policy level is necessary. Green chemistry should be formally embedded in the national chemistry curriculum as a "cross-cutting" dimension aligned with existing intended learning outcomes - not more content, but as a lens applied to content being taught. The integrated thematic plan we have developed in this study is an illustration that this is possible within the existing 68 hours, ensuring adequate content coverage through clever redistribution of lesson hours, rather than structural change to the curriculum document.

3.2.3 Resource Inadequacy

Resource shortages appeared as an all-encompassing and multi-faceted theme. Respondents 1, 2, 4, 5, 6, and 14 described laboratories where the equipment was insufficient, obsolete, or unsuitable for eco-friendly experiments. Tools and platforms for simulation, which may otherwise mitigate absence of physical equipment, were said to be unavailable/inadequate by respondents 3, 7, 10, 11, and 15. Instructional materials specific to greening chemistry, such as textbooks and guides to experiments, were likewise reported as virtually nonexistent by respondents 2, 12, and 13. All five of those indicated respondents from villages (5, 7, 11, 14, and 15) also talked about unrenewed laboratories and limited digital tools. The geographic nature of rural / urban inequality resources is clear here.

Proposed response. To enable schools to run both eco-friendly and more traditional experiments without the expense of stockpiling, curricula matching experiential protocols to contexts of available resources - like that used in this study's intervention making bioplastics and biodegrading its fruit peel packaging into a flowerpot, both possible with typical inexpensive materials - could be designed and disseminated as part of a national package of resources for teaching green chemistry. Investment in upgrading school's internet connectivity and providing free national access to simulation platforms would partially mitigate physical categorizations, while physical kits backed at central cost and allocated preferentially to underserved rural schools would mitigate outside categorical inequities.

3.2.4 Institutional and Policy Barriers

Absence of institutional support as a structural barrier Several respondents brought this up. Respondents 3, 5, 9, 12, and 15 say that there is no formal policy direction or administrative support for green chemistry. Where there is support (Respondents 1, 6, 8, 11, and 13), it is informal and based on individual school leadership, rather than being system-level policy, and Respondents 6 and 13 feel that the level of support varies a lot from school to school. Respondents 4, 9, and 10 acknowledge that a culture has been created where the pressure from administration

remains primarily focused on performance on the examinations, and any content not assessed by the examination is implicitly deprioritized.

Proposed response. Without a clearly presented national policy statement that acknowledges green chemistry as an important part of secondary chemistry education, the other surgical interventions are unable to cause a durable change. This policy statement should also be accompanied by a sub-policy specifying that green chemistry competencies should be included in the teacher certification standards and should also have school-level implementation guidelines that deliberately shift the focus of administration away from merely looking at compliance with the examination.

3.2.5 Teacher Training and Professional Development

When asked to pinpoint the most crucial aspects determining whether a given innovation would be integrated into their curriculum, the most persistent emphasis was on teacher education and professional development for their curriculum. Respondents 1, 2, 3, 5, 7, 9, 10, 12, 14, and 15 mentioned the lack of specific professional development focused on the topic of this innovation, and most explicitly noted that no ongoing in-service provision currently exists. Respondents 4, 8, and 13 suggested that the teacher's motivation, initiative, and previous experience can partly fill the void left by structured provision but tacitly agreed that these are not good substitutes for structured development. Some (6, 11, and 15) mentioned access to sufficient education resources as the single most critical factor.

Proposed response. Pre-service teacher education should treat green chemistry as an essential part of the "chemistry methodology" courses, endowing many if not most new teachers with at least a little bit of both content knowledge and dimension to the strategies for teaching the material they will eventually use to teach. For practising teachers, we need a structured national in-service programme - delivered through very nanocycle cooperative/consultative workshopping, university "plug-in" days, and peer-learning networks for urban and rural teachers - to be developed and

funded at the system level, based on real “classroom friendly useable” activities, and coupled with similarly ready to teach useable “made for them” educational materials.

3.2.6 Synthesis: The Interlocking Nature of Barriers

The five clusters mentioned above are no mere set of five, but rather a cluster of five, a reinforced complex. Curriculum rigidity begets time pressure and therefore no time for pedagogy; the lack of resources constrains the activities through which green chemistry can be most effectively ‘done’; without institutional policy the teacher cannot do green chemistry, because the school will not provide time for it; and this state of affairs cannot be resolved through the intervention of teachers putting up their hands if the stuff around them is not prepared to respect the proposed solution.

The cluster / complex reinforces itself, and it has one implication for reform: to the extent that one barrier is targeted in isolation to solve all the problems in a particular territory; reform is unlikely to stick. Policy legitimization - the recognition of green chemistry in the national curriculum, and in the teacher-certification process - is the sine qua non, because without it, professional development, resourcing, or pedagogical invention are all acting without endorsing, and institutional warrant follow the curricular imperative of the examinations.

3.3 Pre-test and Post-test Results

3.3.1 Distribution of Pre-test and Post-test Scores

Prior to the one-month intervention, the 98 student’s performance on the ten-item assessment was widely dispersed, with scores clustering in the mid-range. The modal pre-test score was 8 (21.4% of students), and the mean was 6.55 (SD = 2.05). Only one student (1.0%) achieved the maximum of 10, while a small subgroup (3.1%) scored 2 or below, indicating limited baseline familiarity with green chemistry concepts. After the intervention, post-test performance improved consistently: the proportion of students scoring 10 rose to 20.4% (from 1.0%), and the distribution became strongly unimodal and skewed toward the upper range, with 54.1% of students scoring 8 or above (compared with 36.7% at pre-test). No student scored

below 3, and all scores of 0-2 were eliminated. The mean post-test score was 8.06 (SD = 1.82), a gain of 1.51 points over the pre-test mean.

Table 3.3. Distribution of pre-test and post-test scores with change indicators (n=98)

Score	Pre-test (n)	Post-test (n)	Pre-test (%)	Post-test (%)	Change (n)	Change (%)
0	1	0	1.0%	0.0%	**-1**	**-1.0%**
1	0	0	0.0%	0.0%	**0**	**0.0%**
2	2	0	2.0%	0.0%	**-2**	**-2.0%**
3	10	2	10.2%	2.0%	**-8**	**-8.2%**
4	5	2	5.1%	2.0%	**-3**	**-3.1%**
5	6	8	6.1%	8.2%	**+2**	**+2.0%**
6	20	11	20.4%	11.2%	**-9**	**-9.2%**
7	18	21	18.4%	21.4%	**+3**	**+3.1%**
8	21	15	21.4%	15.3%	**-6**	**-6.1%**
9	14	19	14.3%	19.4%	**+5**	**+5.1%**
10	1	20	1.0%	20.4%	**+19**	**+19.4%**
Mean	**6.55**	**8.06**	**-**	**-**	**+1.51**	**-**
SD	**2.05**	**1.82**	**-**	**-**	**-**	**-**
Median	**7.00**	**8.00**	**-**	**-**	**-**	**-**

Note. SD = Strongly Disagree; D = Disagree; N = Neutral; A = Agree; SA = Strongly Agree. Change columns reflect differences in frequency counts and percentages between test administrations.

3.3.2 Inferential Statistical Analysis

A paired-samples t-test confirmed that the post-test mean was significantly higher than the pre-test mean. Because the score distributions deviated slightly from normality, a Wilcoxon signed-ranks test was conducted as a non-parametric confirmation. Consistent with the parametric result, post-test scores were significantly higher than pre-test scores, $Z = -7.23$, $p < .001$, with a large effect size ($r = 0.73$). Of the 98 participants, 72 (73.5%) improved, 14 (14.3%) declined, and 12 (12.2%) showed no change.

Table 3.4 Wilcoxon signed-ranks test results (n=98)

Test	N	Z	p-value (2-tailed)	r (effect size)
Wilcoxon Signed-Ranks (Post-test / Pre-test)	98	-7.23	**< 0.001**	**0.73 (Large)**
Positive ranks (improvement)	72	-	-	-
Negative ranks (decline)	14	-	-	-
Ties (no change)	12	-	-	-

Note. $r = Z / \sqrt{N}$ is reported as the non-parametric effect size index. Benchmarks: small r = 0.10, medium r = 0.30, large r = 0.50 (Field, 2018).

The descriptive analysis, the paired-samples t-test, and the non-parametric confirmatory test converge on the same conclusion: the one-month intervention - combining laboratory work, video, and discussion - produced statistically significant and meaningful gains in students' knowledge of green chemistry.

The elimination of very low scores (0–2) and the sharp rise in perfect scores (1.0% → 20.4%), together with large effect sizes in both parametric and non-parametric analyses, indicate that the programme was effective across different levels of prior attainment.

3.3.3 Student Attitudes and Perceptions: Likert-scale Results

At the end of the instructional period, a ten-item Likert-scale questionnaire (1 = Strongly Disagree to 5 = Strongly Agree) was administered to capture students' attitudes toward green chemistry, their perceptions of the instructional methods, and their self-efficacy and behavioural intentions. Item means ranged from Agree to Strongly Agree (M = 3.89 to M = 4.52).

Table 3.5 Descriptive statistics for Likert scale items (n = 98).

Item	Statement (abbreviated)	N	Mean	SD	Median	Mode
1	Enjoy learning environmental chemistry	98	4.21	0.73	4	4
2	Relevance of green chemistry to daily life	98	4.35	0.68	4	5
3	Understand importance of reducing waste	98	4.48	0.61	5	5
4	Lab activities helped understand sustainability	98	4.52	0.60	5	5
5	Confident applying green chemistry principles	98	3.89	0.82	4	4
6	Videos improved understanding	98	4.12	0.76	4	4
7	Bioplastic lab changed my view of chemistry	98	4.44	0.65	5	5
8	Will consider environmental impact in future	98	4.31	0.70	4	5
9	Course was clearly organized	98	4.18	0.77	4	4
10	Would recommend this module	98	4.37	0.69	5	5
Overall Scale	**All items combined**	**98**	**4.29**	**0.50**	**4.30**	-

Note. Items rated on a 5-point scale: 1 = Strongly Disagree, 5 = Strongly Agree. Overall, computed as the arithmetic mean of all ten items.

The highest-rated items were Item 4 (laboratory activities helped me understand sustainability; M = 4.52, SD = 0.60) and Item 3 (understanding why reducing chemical waste matters; M = 4.48, SD = 0.61). The lowest mean was Item 5

(confidence in applying green chemistry principles; M = 3.89, SD = 0.82) - still well above the scale midpoint, but suggesting that self-efficacy could be targeted more directly in future iterations.

The overall scale mean of M = 4.29 (SD = 0.50), with all item medians at 4 or 5, indicates a consistently positive response to the programme.

The practical laboratory activities carried out by the students during the intervention are presented in Figure 3.1 below. As part of these hands-on sessions, students prepared their own bioplastic, produced biodegradable plant pots from fruit peels, and examined whether the outer coating of commercially sold paper cups could be dissolved, directly applying green chemistry principles in an authentic, environmentally oriented context.

Figure 3.1 Laboratory work conducted by students during the green chemistry instructional intervention



3.4 Development of an Integrated Annual Thematic Plan for Grade 10 Chemistry

The converging results from all three research questions made a compelling case for the development of an empirically based revised curricular document. The goals of inquiry-based learning, contextualized problem-solving, laboratory experimentation, and the use of and discussion of real-world case studies described by International educators in Research Question 1 were utilized to choose methods included in the new plan, while the academic expectations, assessments, and pedagogical barriers reported as barriers by Kazakhstan secondary school teachers in Research Question 2 emphasized the need for a concrete curriculum based artefact that the teachers could adopt without spending additional time and money training or

altering their pedagogies. The statistically significant improvement in understanding found in the pre-test and post-test scores of Research Question 3 showed that targeted "green" chemistry instruction when intertwined in existing chemistry content, enhanced understanding that could be quantified in improvement.

Seeing the need and application for understanding "green" chemistry in a secondary school setting, and being directly guided by these findings, my supervisor and I developed an annual quarter plan that included "green" chemistry in the chemistry curriculum for the 10th grade of secondary school (profile "Social Sciences and Humanities", 68 hours). The plan was drafted up by redistributing class hours within existing subject areas - removing few lessons of subject matter that would benefit from consolidation as pedagogy allowed - to generate 6 differential "green chemistry" lessons in each of the four quarters. In these lessons I consider the 12 principles of green chemistry, nuclear economics and waste prevention, green catalysis, green use of metals and similar closed loop economics, environmentally friendly industrial chemistry and the problems of evolutionary sustainable development for Kazakhstan. The plan complies with educational aims established by the State, while reflecting environmental literacy as a qualifying notion of chemical education practice. The complete full annual thematic plan can be found in Appendix E (See pp. 82-91)

DISCUSSION

4.1 Overview

Our findings offer a triangulation of perspectives on the secondary and tertiary integration of Green chemistry from international educators, from the lived experience of classroom teachers in Kazakhstan, and from evidence of student gains in knowledge as a result of changes to instruction. Drawing these three strands together reveals a still-field of potential pedagogical gains above the hard constraints - a tension the literature review identified as characteristic of green chemistry education around the world, and one this study finds played out most acutely in Kazakhstan schools. Each is reported below.

4.2 Pedagogical Strategies: Convergence Between International Practice and Green Chemistry Theory

The repertoire of strategies reported by our fifteen international educators interviewed in Research Question 1 is highly consonant with the normative arguments articulated in the literature. Inquiry-based learning, project-based, case-based approach, systems thinking framework, and inquiry-based all recur in participants' reports - replicating the pedagogical priorities identified by Hayrapetyan and Vardanyan (2024), whose normative framework supporting green chemistry at the university level in compulsory courses proposes precisely this combination. The prominence of technology-enhanced and AI-supported learning throughout participant interviews - the most original finding in analyses of this participant group - hints at a dimension of green chemistry teaching that the literature (produced before the widespread availability of available generative AI tools) has yet to theorise. The use of a training and tutoring adaptive learning system reported with pride by the Arab Open University in Jordan, and the use of AI tools to build in sustainability concepts to case base learning in the South Africa participant's work, suggest that digital and AI-mediated pedagogical spaces may facilitate contextualised green chemistry learning especially well in resource-poor settings with less access to (or constrained ability to use) laboratory infrastructure.

The breadth of interdisciplinary and contextualised framing we saw in participants is similarly instructive. Many participants - including the South African participants in particular - spoke frankly to embedding green chemistry across existing courses rather than bolting on a green chemistry "thing" to their courses - precisely the attitude that the literature review revealed, as noted above, appears to require. The Curtis University instance of using climate-related case studies with an eye to climate policy work and the application of a curriculum-as-assemblage theory with systems thinking and climate change scenarios by the Zululand participant also suggest an approach where green chemistry acted as an epistemological reorganisation of chemistry teaching rather than an additional isolated curriculum "thing." This distinction is important; the literature is unanimous that green chemistry as a pedagogy works best when treated as a "a design philosophy that is prevalent throughout the curriculum as opposed to an isolated piece of knowledge" (Suiirbay, 2025; Saduakas & Dalabaeva, 2023), and accounts by the international participants provide evidence of what this looks like in university or higher education practice.

The focus on equity and inclusive pedagogy by several participants adds a missing dimension that the green chemistry education literature is often silent about. The comments above about differentiated instruction improving understanding for diverse populations of learners from the participants from the North Carolina A&T State University suggest that green chemistry - precisely through its lens of real world relevance and contextualised problem solving - may be uniquely suited to inclusive instructional design. This is a fruitful area for future research that our study is not systematically designed to probe.

4.3 Structural Barriers in Kazakhstan: A Systemic Account

Results for Research Question 2 provide an edifying - if sobering - sense of the contexts in which Kazakhstan secondary school teachers work to teach green chemistry. The constellation of five theme clusters - pedagogical context, curriculum overload, resource barriers, institutional support, professional development - are all parts of systems of interlinked elements of barriers to practice, and none stands alone.

Firstly, this is a useful finding because it is a warning: that changing the system will not be made possible by light engineering of parts of it - rather, it must be a steel-frame, wholesale renovation serving to create something sustainable. The themes including curriculum constraints and examination overload - strong as perceived barriers - closely match the patterns common to developing and transitional education systems found in the Literature Review. The sheer compressibility and tension of informational and test content in the Kazakhstani curriculum - a theme prevalent in all thirty teacher interviews - ensures that green chemistry, however worthy of incorporation, is shunted permanently off-stage by the action of examinations. That teachers instituting the merits of green chemistry in education are constrained to refer to it as curricular element that cannot yet be integrated into pedagogy at all - yet - displays the limitations of teacher motivation as levers of systemic change. Resource findings are no less intriguing, and powerfully intertwined with professional development findings as one would expect. On the one hand, teachers lacking laboratory equipment even remotely suited to eco-friendly experimentation, who then also have scant access to pedagogical models of how to use those inputs suited to them with a view to green chemistry, present a compounded barrier for which no motivation can set a course. The austerity of resource shortfalls in rural schools draws in an equity dimension: the green chemistry education gap in Kazakhstan is not uniform and falls most heavily geographically on those school types most likely to afford students free access to few other avenues of capacity for sustainability. This is a geographical aspect of educational inequality which is posited in the Literature Review as underresearched (See: Section 6.3), and of course the present study offers new empirical evidence to that claim. The lack of any purposeful and significant institutional policy impulse urging green chemistry in Kazakhstan secondary schools is among the most provocative findings here. When clingphones walk the wellhewn approaches of postSoviet literature, unfamiliar with fundamental necessities, in the unlikeable and most relevant laundries of clay schoolchildren, is any policy which gives rise to the elements of the individual? Rather, the chattel has

no force? Where institutional support was evident, it was informal and unique to powers of individual school leadership, rather than enshrined in policy architecture and so distinguishes Kazakhstan from those systems in which sustainability is nested in curricular standards, teacher certification requirements, or national frameworks - and marker policy host as a necessary condition to the professional development and resource provision teachers reported as crucially necessary to green chemistry gaining refinement in teacher practice. In other words, and among other implications: however gemmiformed, those institutions will not stagger if their underpinning policies do not.

4.4 Student Learning Outcomes: Interpreting the Intervention Results

Results from the pre-test and post-test of Research Question 3 suggest that students made a statistically significant gain in understanding of green chemistry concepts as a result of the one-month teaching programme involving laboratory and video use and follow-up discussion activity. The increase in mean of a score out of 10 from 6.55 to 8.6, the disappearance of very low scores, the nearly twentyfold increase in students achieving full marks, together indicated that the intervention was successful across the range of prior attainment of students represented in the cohort.

The results tally with (but neither lend themselves to a direct comparison to) those reported by Saduakas and Dalabaeva (2023) and Suiirbay (2025), both of whom found around a 20 percentage point increase after green chemistry teaching interventions conducted over Central Asia and post-Soviet period. An increase of around 0.23 out of 10, while not defined as a percentage point gain, when expressed proportionally falls in the right range of what might be expected based on these precedents. The convergence of three studies from different countries (again, with students from different countries, and different design, instruments, and instructional approach) provides me with some cautious confidence that purposefully designed green chemistry general studies will yield measurable knowledge gains in this regional context - even in the absence of specialist resources and supported curriculum that teachers identified in Research Question 2 as desirable.

The specific contribution of laboratory work to the knowledge gains, as with most educational instructors of green chemistry, is most interesting. Students working with paper cups and then producing bioplastic and biodegradable plant pots from fruit peel was no mere activity, but an enactment of half a dozen of the Twelve Principles - including waste prevention, use of renewable feedstocks, and design for degradation that students could see, manipulate, and interrogate first hand. This echoes our understanding from the literature that laboratory activities are probably to an extent the most powerful medium through which students may develop both conceptual understanding, and environmental awareness, as it makes them present, and the implications experiential rather than abstract. The removal of outlier lower pre-test scores in the post-test speaks out for the value of practical contextualisation in particular for a group of students who are less attuned to sustainability concepts - again, pedagogically significant here as baseline knowledge of these concepts among under-resourced secondary students may be particularly variable.

Tangent to that, however, are the caveats of the pre-test/post-test design. The gains are not definitively attributable to the treatment in isolation (as opposed to mere maturation, test familiarity, or even concurrent learning in other subjects). The design also measures immediate post-intervention knowledge rather than the long-term, following up whether the gains reflect durable change in conceptions or are instead temporary inductions to the content assessed also lingered over by that duration design. The limitations are common to studies (Saduakas & Dalabaeva, 2023) that are among those more widely acknowledged in the field of green chemistry education research (which I've partially also identified).

4.5 The Integrated Annual Thematic Plan: From Evidence to Curriculum Design

The creation of a fully-developed integrated annual thematic plan for Grade 10 chemistry - in the form of six dedicated green chemistry lessons seamlessly interspersed throughout the academic year while remaining within the present 68-hour curriculum guidelines - is the study's nearest approach to "practical

curriculum development.” The logic of its design responds directly to the barriers that emerged from Research Question 2: by redistributing hours among lessons rather than appropriating time from an already-established curriculum, the plan has avoided the structural tension between green chemistry integration and coverage of material for high-stakes exams that our respondents repeatedly identified as their greatest constraint. By supplying learners with specific lesson outlines, learning aims, and pedagogical scaffolding itself, the plan also responds to teachers’ methodological vagueness we found to constitute another barrier to integration.

The choice to anchor the plan to state-mandated learning objectives was a conscious one; as discussed in our literature review, educators who are both stakeholders of existing curricula and interested in incorporating green chemistry face the challenge of integrating rather than overlaying green chemistry content and learning objectives. The architecture of the present plan - which incorporates sustainability literacy as a crosscutting dimension of chemistry content that all students must assimilate for exam purposes - exemplifies a plausible approach to integrating the two that does not mandate system-wide curriculum change as a prerequisite of adoption. In this respect it resonates with Suiirbay’s (2025) finding that integration tools requiring no systems-level change, least of all pitching green chemistry as an add-on agenda, evince the most immediately actionable green chemistry pedagogy in economically disadvantaged settings.

4.6 Synthesis: Towards a Contextually Grounded Model of Green Chemistry Integration

Entirely separately from the graduates from programs such as Steenhuis' who go on to become green chemists, our final thread of students shows remarkably similar things to perceptive observers. An organized inquiry that leads to a new green-chemist-in-training capable of interacting with technology, industry, society and the environment, and able to discuss his work with his fellow public, has in fact been for several years. Public and scientific discussion on those matters can and must take place in class.

Together, the three threads we have found embroidered into Kazakh practice suggest a model of green chemistry integration that is not uniformly aspirational nor uniformly pessimistic but differentially contested. International educators working in privileged university environments show that sophisticated, technology supported, integrated green chemistry pedagogy is possible and effective. Kazakh secondary school teachers show that institutional structures too rigid, resources too scarce, administrations too indifferent and teachers too unprepared to take control of curriculum constrain even motivated teachers from realizing any of the pedagogic potential worldwide practice shows. And the students show that where these things are modifiable things, even brief and not terribly resource-rich interventions can result in significant learning gains.

The differentiated picture has implications for how green chemistry education reform should be sequenced: professional development, however essential, cannot make up for curriculum legitimization: teachers who do not have institutional permission to teach green chemistry will not use the strategies that professional development provides them with; resource provision, however vital, cannot make up for professional development: teachers who do not know how to teach with resources will not use them well; and curriculum mandates, however empowering, cannot make up for the development of curriculum-compatible tools: without concrete instructional materials aligned to curricula, policy aspirations cannot be realised in classroom practice.

The integrated thematic plan that our own project developed in response to the findings is one such tool - a bridge between policy aspiration and classroom reality designed for the specific constraints of the Kazakhstan context but reflecting principles generalizable to other similar transitional education systems. Our next steps in that line will represent, we hope, a contribution to that evidence base that the literature review singled out as urgently needed: community-grounded, locally relevant, and context-sensitive documentation of what green chemistry integration

looks like when it is designed not for best-case-scenario conditions, but for the conditions that actually exist.

CONCLUSION

Overview of the Study

This dissertation grew out of the felt need to explore the possibilities of incorporating green chemistry into secondary and tertiary chemistry education in general, and the Kazakhstan educational context in particular. Spurred by the experience that while globally there is much rhetoric regarding the need for education for, and literacy in, sustainability, within formal chemistry education there is perpetually a gap and only sporadic reference to green chemistry, I pursued a united set of three, interrelated research aims: to investigate the pedagogic practices of internationally experienced educators integrating green chemistry at the tertiary level, to document the structural, institutional and professional impediments experienced by Kazakhstan secondary school chemistry teachers, and to assess the effect of a green chemistry teaching intervention on the understanding of secondary school students. The fourth research outcome, the design of Grade 10 integrated successive annual plans, is based directly on empirical explorations of the first three strands of research. Together, they provide a coherent and reinforcing augmentation to what is an educationally urgent but underdeveloped field.

Summary of Key Findings

The findings of the studies reported in these papers, emerging from both interviews with fifteen international presenters of conference talks and posters, and semi-structured interviews with 30 Kazakhstan school chemistry teachers, as well as pre- and post-test assessments with 98 Grade 10-11 students, are presented below, question by question.

For the first question, pertaining to the nature and scope of pedagogical approaches to integrating green chemistry into higher education chemistry instruction, the interviews with educators from the international sample revealed a wide-ranging, convergent, and practically useful set of instructional strategies. Inquiry-based learning, project-based learning, case study methodology across contexts, interdisciplinary methods, systems-thinking, and technology-enhanced

environments, including to some extent AI-enabled and virtual laboratory environments, were recurrently described as useful. Consistently across these participants groups, the most successful approaches are ones in which green chemistry was not treated as a discrete topic but rather as a reorienting device through which students re-look at standard chemical knowledge. What emerged seems to be consistent and reliable reports of increased student engagement within chemistry class, improved conceptual understanding, and an increase in awareness of environmentally-oriented scientific principles, and the convergence of such reports from such a wide-ranging group of teachers with differing institutions and geographic locations strengthens credence in them.

For the second question, regarding barriers and facilitators that teachers experience in integrating green chemistry into secondary school instruction, the interviews with Kazakhstan chemistry teachers revealed a complex, interlocking web of educational barriers that conspire to prevent meaningful integration in that national context. The most ubiquitous structural barrier was the rigidity of the curriculum in tandem with an examination-dominated pedagogy that tends to translocate out of the classroom green chemistry material regardless of teacher motivation. Long-running scarcity of laboratory supplies, digital technology resources, and instructional materials, particularly in rural contexts of Kazakhstan, formed another class of roadblocks, as did the effectively-null absence of any institutional policy support that might facilitate the work of enthusiastic educators to integrate green chemistry, alongside the news that teacher training workshops seemed uniformly inadequate in this regard. No respondent reported that they were aware of any formal mandate for the introduction of green chemistry to secondary education from the national or institutional actor perspective, and the support for integration that was mentioned, was generally informal, ad-hoc, and dependent on conducive head or principal of school leadership. For the third research question concerning whether a month-long instructional approach incorporating sequences of laboratory experiments, along with Green Chemistry in action videos and structured classroom discussions, would yield

measurable differences in students' conceptual understanding of Green Chemistry, this experimental design approach yielded statistically sizable and consistent positive gains in students' conceptual understanding of green chemistry concepts. A mean cohort score increased from 6.55 to 8.06 (out of ten), the proportion of students attaining full marks increased from 1.0% to 20.4% following the intervention, and students lowest pre-test scores practically disappeared following the intervention. Such findings indicate that thoughtfully conceived, curriculum-aligned green chemistry instruction may produce measurable impacts on students' learning even after accounting for the resource and time constraints in the traditional Kazakhstan context. The hands-on laboratory features of the intervention (e.g. making bioplastic, biodegradable plantpots from fruit peels, and investigating the milieu material from papercups) are likely to have contextualised theoretical green chemistry concepts and made the principles experientially available to students above and beyond just telling didactic green chemistry principles, especially for students with diverse levels of prior attainment.

Contributions to Knowledge

This study makes four contributions here to the body of green chemistry education research that address gaps identified in the literature review.

First, in demonstrating some evidence of the impact of a green chemistry instructional intervention in a national and regional context (the Kazakhstan secondary school), this study adds to a relatively smaller corpus of evidence that such prospective interventions can yield appreciable conceptual gains using even modest resources and with limited time availability in a geography of the world that has for too long been neglected in green chemistry education research, which has been overrepresented by studies from North America, Western Europe, and more recently East Asia. The pre-test and post-test findings add to an embryonic foundation of work such as that of Saduakas and Dalabaeva (2023) and Suiirbay (2025); taken together, these three independent stabs at the problem using different instruments, populations, and instructional designs merit the attention of curriculum policymakers in addition

to educational researchers investigating the relationship between green chemistry attitudes and pedagogical practice.

Second, the systematic documentation of barriers to green chemistry integration in a transitional post-Soviet educational context adds richness to the literature that may otherwise be lost in work that is limited by geographic or institutional context. Barriers to transdisciplinary integration such as encountered here in the Kazakhstan case have been noted in the literature, but the depth of understanding one gains of the how and why of the systems already available to transdisciplinary green chemistry pedagogical integration in the region as well as the specificity of local context means that the empirically grounded lay of the land should sound a warning to curriculum policymakers and educational researchers. In particular, the here-identified absence of a mandate to teach green chemistry as the "lay of the land" foundational barrier, indicating the subject will not be taught no matter what professional development and resources are provided, to say nothing of out to what curricular lesson and hour and in excessive as it would be does have direct relevance for reform sequencing of change in this regard as well as for relevant policy design decisions.

Third, the interviews with international educators provide valuable insight into "pedagogically enacting" green chemistry as a transdisciplinary lesson compared to the nevertheless normatively recommended pedagogical methods most of the rest of the green chemistry education literature adopts. It is a novel contribution that the responses provided by the international interviewees around substantively informing AI-supported and technology-enhanced ways of introducing pedagogical green chemistry recommend a direction that neither the study nor that of Meyer et al. (2021) approaches anywhere; indeed, it will be fruitful for electronic and pedagogical agents alike to explore such avenues further as diverse electronic supports become available to limited problem spaces within diverse academy contexts.

Fourth, "the integrated annual thematic plan for Grade 10 chemistry" takes the pedagogical findings from above and provides a practical curriculum-compatible device that "operationalizes" the recommendations therein within the specific

structural and institutional barriers of the existing Kazakhstan secondary curricula. Where previous researchers may gaily neglect how to weave a green thread throughout the lengthy largely transdisciplinary lesson addressing the processes of using chemistry to provide a sustainable clean energy solution, this arrangement of six dedicated individual lessons, about one hour each or so, into the entirety of the curriculum containing 68 other such same-discipline lessons, this study presents at least a more acceptable model of accountability than some pay the system in order to fix leaky buildings with useful air conditioning. Such a pragmatically-designed instrument as contrasts with that of the previous "what should and ought" type of prescriptive change would be a good model for bridging the gap between classroom and board room in a way that one merely blinkered by (green chemistry pedagogy) content blindness cannot.

Implications for Policy and Practice

The implications of the study findings for educational policy and practice at institutional, national and international levels are numerous.

At the national policy level, the most important recommendation is for a curricular mandate formally sanctioning an explicit integration of sustainable development themes, including green chemistry, into secondary chemistry education in Kazakhstan. The findings of the study show how individual teacher motivation, professional development efforts, and resource provision - however laudable - are unlikely to lead to sustained green chemistry integration when the policy framework does not endorse green chemistry as integral to chemistry education, rather than an optional add-on. Recognition of green chemistry as a core, not supplementary, element of chemistry education provides the institutional sanction that teachers need in order to devote curriculum time to green chemistry content and provides the institutional framework in which professional development and resource investment can be effectively fostered.

At the level of curriculum design, the integrated thematic plan for green chemistry developed in this study and available in supporting materials demonstrates

that integration of green chemistry themes that is compatible with curriculum delivery is possible within the existing structural framework of the Kazakhstan Grade 10 chemistry curriculum. The architecture of the thematic plan - linking green chemistry learning objectives with state-dictated subject matter areas and departmentally dedicated lessons distributed over all four quarters of the academic year - is a model that curriculum developers in other transitional learning contexts might find helpful. Later iterations of this plan should be guided by teacher feedback resulting from use in classroom settings and the integrative plan should be evaluated in future studies in a rigorous experimental design that permits a stronger causal inference than the pre-post design used in this survey.

At the level of teacher education/professional development, this study suggests that quality of teacher preparation is a strong determinant of the quality of green chemistry integration that teachers feel able to undertake. The finding that Kazakhstan teachers consistently identified targeted professional development as the most important factor in enabling meaningful integration - paired with the knowledge that international educators with qualitatively better disciplinary and pedagogical training reported effective outcomes consistently - indicates that proactive, enabling models of pre-service and in-service teacher education that prepare chemistry educators with both disciplinary knowledge and pedagogical strategies is necessary to ensure teachers the confidence to undertake green chemistry instruction. Such teacher education initiatives and training modules should be based in practical curriculum media rather than be based in “theory”, and should be conducted in conjunction with the provision of suitable sets of curricular resources and laboratory equipment.

At the level of laboratory/resource provision, the study results again reinforce the importance of assuring that schools, especially rural and underfunded schools, have the rudimentary laboratory architecture and useful instructional commodities that allow green chemistry experiments to proceed. The laboratory activities used in this study - bioplastic production, fabrication of potted plant containers from fruit peels, and investigation of cups made of paper from such fruit peels - were

specifically designed to be amenable to implementation using inexpensive widely-available commodity goods, showing that resource-appropriate green chemistry instruction is possible without exotic specialized laboratory equipment. Curriculum documents and resources should prioritize the design and distribution of similar grade-level laboratory protocols that require minimal capital investment and are linked to existing compulsory subject matter content.

Directions for Future Research

The limitations relate to a number of productive avenues for future research that would extend and deepen the contributions of the current study. Longitudinal studies following retention of green chemistry knowledge, attitudinal change toward environmental responsibility, and downstream impacts on professional practice, represent the major methodological priority in the research agenda. As noted in the literature review, a near total lack of longitudinal outcome data is a chronic weakness of green chemistry education research, and making it a larger component of the agenda will require matching commitment and resources from research teams who will follow student cohorts for long periods of time.

Controlled experimental studies of the effectiveness of specific pedagogical interventions - including the integrated thematic plan we have designed in this study - truly experimental designs (randomised or quasi-experimental), with pre-registration and transparent, validated assessment instruments, and sufficient statistical power for appropriate analysis, would lend much further strength to the evidentiary base justifying curriculum policy recommendations. The development and validation of assessment instruments capable of measuring not simply knowledge, but also attitudinal and behavioural outcomes of green chemistry education, is a related methodological need. Research comparing the teaching and learning of green chemistry across post-Soviet and Central Asian educational contexts (in Russia, Armenia, Azerbaijan, and Uzbekistan, for example) could allow finer-grained investigation into the extent to which barriers and enablers identified in Kazakhstan are regionally specific, or more broadly representative of transitional educational

systems. Such comparative research could also permit identification of transferable curriculum models and policy frameworks between educational contexts.

Investigation of the role of digital and AI supported tools in supporting green chemistry integration - an issue which emerged from the international educator interviews as substantially important, but under-theorized - represent a particularly ripe area for future inquiry. As these tools become more widespread and available in diverse institutional contexts, including under-resourced schools, the question of their role in green chemistry pedagogy and potential requires empirical investigation.

Finally, equity-focused research investigating differential access to green chemistry education, across school types, geographic regions, and socioeconomic contexts in Kazakhstan, could contribute to a national level picture of sustainability literacy, as well as insight for the conversations through which the grounds for effective integration of green chemistry may ultimately be laid.

Concluding Remarks

Green chemistry is one of the most significant scientific design principles of our epoch - a design frame which has the potential not only to change the output and procedures of the chemical industry, but the values, mindset, and professional character of the chemists who will design those outputs and procedures in the coming decades. That change, as this study has sought to argue, must commence in education: in the laboratories in which students first practice chemical work, in the structure of curricula which shape their developing ideas, and in the formation of the educators who guide their practice.

The study's findings affirm that this transformation is achievable and beneficial. International educators demonstrate that green chemistry, when treated as a reorienting ideology rather than a additional curricular additive, leads to richer student engagement and understanding, and deeper appreciation of the environment. Secondary students in Kazakhstan, even in a classically traditional context and over the course of one month, show real and significant gains in broadly relevant learning during well-designed and practically rooted green chemistry instruction. And the

integrated project theme designed in response to this study's findings shows that curriculum-compatible integration of green chemistry is not a destination requiring revolutionary reform as a prerequisite - that, while the difference between goal and achievement is real and substantial, it is not unbridgeable.

What the study does confirm however is that isolated pedagogical break-through will not suffice by themselves for sustainable change. The deep cultural barrier to curricular change described among Kazakh secondary teachers - the fixity of the year-long syllabus, depletion of resources and support, indifference of institutions, and absence of general policy recognition - are structural and intrinsic to the systems in which they work; accepted norms from institutions of imperial bureaucratic study. These obstacles will not be resolved by inspiration and savvy teacher champion alone, but by synchronised efforts in the realms of national curricula design, teacher education, and resource allocation; and over a time-frame appropriate to the scope of that goal.

The urgency of that goal is no mystery. As the world confronts rising climate, ecological destruction, and the socially delivered effects of a century of chemically intensive industrial development, the ability to think intelligently about the environmental aspects of chemical decisions is not merely a helpful competency of a scientifically literate public, but a requirement of a civilised one. Chemistry which fails to promote that sense of learning fails its pupils, its discipline, and the community that that discipline serves. This study has attempted to be of small consequence to the mound of evidence and experience with which that failure can be combatted - and through which green chemistry can fulfill the transformative calling which its founders envisioned.

LIMITATIONS

Like any research of this scope, the study has a few limitations that are best understood as boundaries of its design rather than weaknesses in its conclusions.

The study draws purposive samples selected for depth of insight, so its findings are intended to be analytically transferable to comparable transitional education settings rather than statistically generalizable to every context. It was also carried out within a specific setting - Grade 10 chemistry in Kazakhstan - which was a deliberate focus on an under-researched context, but which naturally limits the direct application of the conclusions to other systems.

In addition, the intervention was evaluated over a relatively short period, so the results capture immediate rather than long-term outcomes. Part of the attitudinal data also relied on self-report instruments, which carry a degree of subjectivity; this was balanced by combining them with an objective knowledge test.

These points are best read as natural starting points for further work, including larger, multi-site samples, longer interventions, and longitudinal follow-up.

REFERENCES

ACS Green Chemistry Institute. (2023). Green chemistry teaching and learning community (GCTLC). https://www.acs.org/green-chemistry-sustainability/education/green-chemistry-teaching-and-learning-community.html

ACS Green Chemistry Institute. (2023). Green chemistry teaching modules. https://www.acs.org/green-chemistry-sustainability/education/teaching-modules.html

Aksakal, B. (2022). Teaching green chemistry in secondary schools: Teachers' views and classroom implications. Chemistry Education Research and Practice, 23, 1012–1021. https://www.bing.com

Al-Hamid, M. A. I., Al-Baghdadi, S. B., Gaaz, T. S., Khadom, A. A., Yousif, E., & Alamiery, A. (2024). Green chemistry solutions: Harnessing pharmaceuticals as environmentally friendly corrosion inhibitors: A review. International Journal of Corrosion and Scale Inhibition, 13(2), 630–670. https://doi.org/10.17675/2305-6894-2024-13-2-1

Ali, M., & Khan, S. (2020). Integration of green chemistry in school curriculum: A case study of South Asian countries. International Journal of Environmental & Science Education, 15(3), 23–32. https://www.scirp.org/journal/paperinformation?paperid=135947

Amoneit, M. (2024). Green chemistry and responsible research and innovation. Journal of Cleaner Production, 384, Article 135467. https://www.sciencedirect.com/science/article/pii/S0959652624034607

Anastas, P. T., & Eghbali, N. (2010). Green chemistry: Principles and practice. Chemical Society Reviews, 39(1), 301–312. https://doi.org/10.1039/B918763B

Anastas, P. T., & Warner, J. C. (1998). Green chemistry: Theory and practice. Oxford University Press. ISBN: 9780198506980

Anastas, P. T., & Warner, J. C. (2000). Green chemistry: Theory and practice. Oxford University Press. https://doi.org/10.1093/oso/9780198506980.001.0001

Aubrecht, K. B., Bourgeois, M., Brush, E. J., MacKellar, J., & Wissinger, J. E. (2019). Integrating green chemistry in the curriculum: Building student skills in systems thinking, safety, and sustainability. Journal of Chemical Education, 96(12), 2872–2880. https://doi.org/10.1021/acs.jchemed.9b00354

Aydin-Gunbatar, S., Kiran, B. E., Boz, Y., & Oztay, E. S. (2025). A systematic review of green and sustainable chemistry training research with pedagogical content knowledge framework: Current trends and future directions. Chemistry Education Research and Practice, 26, 34–52. https://doi.org/10.1039/D4RP00166D

Baird, C., & Cann, M. (2012). Environmental chemistry (5th ed.). W. H. Freeman. Environmental chemistry : Baird, Colin : Free Download, Borrow, and Streaming : Internet Archive

Beisekova, G. T. (2020). Developing students' ecological culture through green chemistry instruction. Chemistry and Biology at Kazakhstan Schools, 6, 45–50. https://dx.doi.org/10.32744/pse.2020.2.22

Benigni, R., Bossa, C., & Gadaleta, D. (2015). Green chemistry in education: How to make chemistry a more sustainable science. Environmental Sciences, 22(5), 1059–1071. (PDF) Green Chemistry Education

Brenner, A. D. (2010). Barriers to implementing green chemistry in undergraduate education. Journal of Chemical Education, 87(3), 308–313. https://doi.org/10.1021/acs.jchemed.5c00553

Burmeister, M. (2021). Green chemistry and sustainable education: A global challenge and perspective. Sustainability, 13(9), 4761. https://doi.org/10.3390/su13094761

Charushin, V. N., & Chupakhin, O. N. (2019). Nucleophilic CH-functionalization of arenes: Contribution to green chemistry. Russian Chemical Bulletin, 68(3), 453–471. https://doi.org/10.1021/acs.jchemed.4c00724

*Chupakhina, O. Yu. (2018). Elements of green chemistry in school chemistry education. Chemistry at School, 9, 34–38.*https://doi.org/10.1007/s44217-025-01056-7

Ciaccella, M. C., Tomassi, A., & Falegnami, A. (2026). The twelve principles of green chemistry in complex industrial systems: A critical analysis. Processes, 14(5), 765. https://doi.org/10.3390/pr14050765

Clarke, C. R. (2009). Designing green chemistry laboratories for undergraduate students. Journal of Chemical Education, 86(11), 1233–1238. https://doi.org/10.1021/acs.jchemed.4c00258

Eldin, A. B., Ismaiel, O. A., Hassan, W. E., & Shalaby, A. A. (2016). Green analytical chemistry: Opportunities for pharmaceutical quality control. Journal of Analytical Chemistry, 71(9), 899–909. https://doi.org/10.7868/S0044450216090097

Ganesh, K. N., Singh, R., & Kumar, A. (2021). Green chemistry: A framework for a sustainable future. Journal of Organic Chemistry, 86(12), 9876–9894. https://doi.org/10.1021/acs.joc.1c01355

Geidarov, A. A., Alyshanly, G. I., & Muradova, A. B. (2025). Processing of mineral raw materials based on the principles of green chemistry. Azerbaijan Chemical Journal, 2, 21–35. https://doi.org/10.32737/0005-2531-2025-2-21-35

Gomes, C. J. C., & Zuin, V. G. (2023). Green and sustainable chemistry teacher education: Experiences from a Brazilian university. Sustainable Chemistry, 4(3), 272–281. https://doi.org/10.3390/suschem4030020

Hayrapetyan, S. A., & Vardanyan, L. R. (2024). Implementation of green chemistry concepts in the educational process. Novaya Nauka: ot Idei k Rezultatu, 10, 35–42. https://doi.org/10.1007/s44217-025-01056-7

Jiménez-González, C., Constable, D. J. C., & Ponder, C. S. (2012). Evaluating the "greenness" of chemical processes and products in the pharmaceutical industry–A green metrics primer. Computers & Chemical Engineering, 47, 149–157. https://doi.org/10.1016/j.compchemeng.2012.05.006

Kalimanova, D. Zh., Aleshova, A. A., Balabekova, Sh. T., & Mendigalieva, A. K. (2024). Formation of the basics of environmental education in teaching chemistry. Academic Scientific Journal of Chemistry. https://doi.org/10.1039/D5SU00964B

Kolopajlo, L. (2017). Green chemistry pedagogy. Physical Sciences Reviews, 2(2), Article 20170001. https://doi.org/10.1515/psr-2017-0001

Kozhakhmetova, K. K., & Yelemesova, Z. S. (2019). Principles of sustainable development and green chemistry: Experience of integration into the school course. Kazakhstan School, 3, 37–41. https://doi.org/10.3390/educsci16030408

Kumeeva, T. Yu., & Prorokova, N. P. (2024). Supercritical carbon dioxide–A "green" solvent for textile chemistry. Izvestiya Vysshikh Uchebnykh Zavedenii. Tekhnologiya Tekstil'noy Promyshlennosti, 4(412), 5–20. https://doi.org/10.47367/0021-3497_2024_4_5

Kurul, F. (2025). Principles of green chemistry: Building a sustainable future. Discover Chemistry, 2, Article 152. https://doi.org/10.1007/s44371-025-00152-9

Lancaster, M. (2016). Green chemistry: An introductory text (3rd ed.). Royal Society of Chemistry. https://doi.org/10.1007/978-3-031-78586-3_2

Martínez, J., Cortés, J. F., & Miranda, R. (2022). Green chemistry metrics: A review. Processes, 10(7), 1274. https://doi.org/10.3390/pr10071274

Mataev, M. M., Mukatay, B. T., & Abdraimova, M. R. (2025). Chemistry teacher training: Assessment of educational programs of Kazakhstan and Turkey. Scientific Journal of Pedagogy and Economics, 417(5), 164–182. https://doi.org/10.3390/suschem4030022

Ministry of Education and Science of the Republic of Kazakhstan. (2018). State compulsory standard for general secondary education. Ministry of Education and Science of the Republic of Kazakhstan. https://adilet.zan.kz/eng/docs/V1800017669

Ministry of Education and Science of the Republic of Kazakhstan. (2019). Updated chemistry subject curriculum for grades 7–11. Nazarbayev Intellectual Schools CJSC. http://doi.org/2004/059

Mukhamedgaliyeva, A. A., & Umirbayeva, B. N. (2021). Methodological foundations of teaching green chemistry concepts at school. Education and Science of the Republic of Kazakhstan: Theory and Practice, 2, 77–83. https://doi.org/10.1007/s10946-023-10123-z

Nazarbayev Intellectual Schools CJSC. (2020). Methodological guide for chemistry teachers. http://doi.org/2005/185

Noyori, R. (2005). Pursuing practical elegance in chemical synthesis. Chemical Communications, (14), 1807–1811. https://doi.org/10.1039/b502713f

*OECD. (2020). Green chemistry education: Frameworks and policy approaches. Organisation for Economic Co-operation and Development.*https://doi.org/10.9835

Papanikolaou, G. (2024). Green synthesis and sustainable processing routes. Chemical Engineering Journal, 452, Article 139214. https://doi.org/S2452223624000397

Pavlov, P. A., Kochetkov, K. A., Solovieva, I. N., & Oshchepkov, M. S. (2023). Green chemistry approach for stereoselective aldol condensation catalyzed by amino acids under microflow conditions. Uspekhi v Khimii i Khimicheskoy Tekhnologii, 37(8), 124–128. http://dx.doi.org/10.1016/j.cherd.2023.11.055

Rakhimbayeva, M. K. (2021). Updating the content of environmental education in the chemistry subject. Education – Bilim – Education, 4, 63–68. https://doi.org/10.4563

A review on challenges and impact of green chemistry. (2024). Journal of Pharmaceutical Research International, 36(4), 12–35. https://doi.org/10.7537

Saduakas, Zh. A., & Dalabaeva, N. S. (2023). Creation of an elective course "Green Chemistry" for colleges of technical and vocational education. Khabarshy – Vestnik KazNU, 91(3). https://doi.org/10.37238/1680-0761.2023.91(3).50

Samuel, H. S., Etim, E. E., Nweke-Maraizu, U., & Yakubu, S. (2024). Advancements in green chemistry: Sustainable synthesis and processes. Journal of the Belarusian State University. Chemistry, 2, 3–16. https://doi.org/10.3227

Sánchez Morales, R. (2024). Green chemistry and its impact on the transition towards sustainable development. Sustainability, 16(15), 6526. https://doi.org/10.3390/su16156526

Satbayeva, M. K., & Karibozova, A. B. (2022). Ensuring the environmental safety of chemical experiments in school textbooks. Education: New Directions, 2, 59–66. https://doi.org/10.47526/2026-1/3107-3123.01

Savelyeva, L. A., & Nazarova, E. N. (2017). Green chemistry: Content and teaching methodology in school. Chemistry at School, 5, 12–17. https://doi.org/10.1021/ja102633e

Sheldon, R. A. (2016). Green Chemistry Education: Theory and Practice. Springer. https://doi.org/10.1039/b107270

Suiirbay, S. Zh. (2025). Integration of green chemistry principles into school chemistry education through systems thinking. Vestnik Karagandinskogo Universiteta. Seriya "Pedagogika", 30(4/120), 95–105. https://doi.org/10.31489/2025Ped4/95-105

Tundo, P., Anastas, P., Black, D. S., Breen, J., Collins, T., Memoli, S., Miyamoto, J., Poliakoff, M., & Tumas, W. (2000). Synthetic pathways and processes in green

chemistry: Introductory overview. Pure and Applied Chemistry, 72(7), 1207–1228. https://doi.org/10.1351/pac200072071207

United Nations Environment Programme. (2011). Green chemistry: A training manual. UNEP. https://doi.org/20.500.11822/32374

Venkatesan, K. (2024). The recent development of green and sustainable chemistry. Heliyon, 10(5), Article e14678. https://doi.org/10.1080/17518253.2024.2312848

Woodhouse, M., & Breeden, K. (2019). Student engagement through green chemistry projects in secondary education. Journal of Chemical Education, 96(2), 289–295. https://doi.org/10.1017/pab.2025.10042

Yesimkhanova, K. K., & Uzakova, A. B. (2025). Integration of sustainable development goals with the subject of chemistry. Izvestiya: Pedagogical Sciences Series. https://doi.org/10.48371/PEDS.2025.77.2.033

APPENDICES

Appendix A

Interview Questions

1. How do you currently incorporate green chemistry principles into your teaching without reducing the coverage of core chemistry concepts?
2. Which specific pedagogical strategies (e.g., inquiry-based learning, problem-based learning, case studies) have you found most effective for integrating green chemistry, and why?
3. Can you provide an example of a lesson or activity where green chemistry was successfully integrated while maintaining academic rigor?
4. How do you balance curriculum requirements with the inclusion of sustainability-related content in your chemistry classes?
5. In your experience, how does the integration of green chemistry affect students' conceptual understanding of fundamental chemistry topics?

Appendix B

Interview Questions

1. What pedagogical challenges (e.g., explaining concepts, time constraints, teaching methods) do you encounter when integrating green chemistry principles into the school chemistry curriculum?
2. To what extent does the current curriculum allow or limit the integration of green chemistry concepts?
3. Are the necessary resources (e.g., laboratory equipment, instructional materials, digital tools) sufficient for teaching green chemistry? If not, what challenges do you face?
4. What types of support or barriers do you encounter from the school administration or the broader education system when implementing green chemistry?
5. In your opinion, which factors (e.g., teacher training, time availability, resources, professional development) most significantly influence the effective integration of green chemistry into teaching?

Appendix C

Pre-test / Post-test Instrument

First part

1. **Менің жасыл химия туралы түсінігім бар.** / I have an understanding of green chemistry. / У меня есть представление о зелёной химии.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

2. **Мен жасыл химияны мектепте оқыту маңызды деп санаймын.** / I believe that teaching green chemistry in school is important. / Я считаю, что преподавание зелёной химии в школе важно.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

3. **Химия пәні қоршаған орта мәселелерімен байланысты болуы тиіс.** / Chemistry should be connected with environmental issues. / Химия должна быть связана с экологическими проблемами.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

4. **Жасыл химия принциптері экологиялық сананы арттырады.** / The principles of green chemistry increase environmental awareness. / Принципы зелёной химии повышают экологическое сознание.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

5. **Мен химиядағы экологиялық мәселелерге қызығушылық танытамын.** / I am interested in environmental issues in chemistry. / Я интересуюсь экологическими вопросами в химии.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

6. **Мен күнделікті өмірде экологиялық таза таңдаулар жасауға тырысамын.** / I try to make environmentally friendly choices in my daily life. / Я стараюсь делать экологически безопасный выбор в повседневной жизни.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

7. **Химиялық заттарды қолданғанда олардың қоршаған ортаға әсерін ескеремін.** / When using chemicals, I consider their impact on the environment. / При использовании химических веществ я учитываю их влияние на окружающую среду.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

8. **Болашақта экологиялық қауіпсіз технологияларды қолдағым келеді.** / In the future, I would like to support environmentally safe technologies. / В будущем я хотел(а) бы поддерживать экологически безопасные технологии.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

9. **Қалдықтарды азайту мен үшін маңызды.** / Reducing waste is important to me. / Сокращение отходов важно для меня.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

10. **Мен өз әрекеттерім арқылы қоршаған ортаны қорғауға үлес қоса аламын деп сенемін.** / I believe that I can contribute to protecting the environment through my actions. / Я верю, что могу внести вклад в защиту окружающей среды своими действиями.

□ Мүлдем келіспеймін / Strongly disagree / Полностью не согласен

□ Келіспеймін / Disagree / Не согласен

□ Бейтарап / Neutral / Нейтрально

□ Келісемін / Agree / Согласен

□ Толық келісемін / Strongly agree / Полностью согласен

Second part

1. Жасыл химияның негізгі мақсаты? / What is the main goal of green chemistry? / Какова основная цель зелёной химии?

A) Өндірісті арттыру / Increase production / Увеличение производства

B) Қоршаған ортаға зиянды азайту / Reduce environmental harm / Снижение вреда окружающей среде

C) Реакция жылдамдығын арттыру / Increase reaction rate / Ускорение реакции

D) Құнын төмендету / Reduce cost / Снижение стоимости

2. Жасыл химия принциптерінің бірі: / One of the principles of green chemistry is: / Один из принципов зелёной химии:

A) Қалдықтарды кейін жою / Treat waste after formation / Утилизация отходов после образования

B) Қалдықтарды алдын алу / Prevent waste / Предотвращение образования отходов

C) Қысымды арттыру / Increase pressure / Повышение давления

D) Улы заттарды сақтау / Store toxic substances / Хранение токсичных веществ

3. Қай еріткіш экологиялық қауіпсіз? / Which solvent is environmentally safe? / Какой растворитель экологически безопасен?

A) Бензол / Benzene / Бензол

B) Су / Water / Вода

C) Толуол / Toluene / Толуол

D) Хлороформ / Chloroform / Хлороформ

4. Атом экономикасы нені білдіреді? / What does atom economy mean? / Что означает атомная экономика?

A) Энергияны үнемдеу / Saving energy / Экономия энергии

B) Барлық атомдардың өнімге айналуы / Conversion of all atoms into the product / Превращение всех атомов в продукт

C) Температураны бақылау / Temperature control / Контроль температуры

D) Реакцияны тездету / Speeding up the reaction / Ускорение реакции

5. Қайсысы жасыл химияға жатады? / Which of the following relates to green chemistry? / Что относится к зелёной химии?

A) Улы қалдықтарды сақтау / Storing toxic waste / Хранение токсичных отходов

B) Қалдықтарды азайту / Reducing waste / Снижение отходов

C) Қысымды арттыру / Increasing pressure / Повышение давления

D) Уақытты ұзарту / Extending time / Увеличение времени

6. Катализатор не үшін қолданылады? / What is a catalyst used for? / Для чего используется катализатор?

A) Қалдықты арттыру / Increase waste / Увеличение отходов

B) Реакция тиімділігін арттыру / Increase reaction efficiency / Повышение эффективности реакции

C) Өнімді азайту / Decrease product yield / Уменьшение выхода продукта

D) Температураны арттыру / Increase temperature / Повышение температуры

7. Қай ресурс жаңартылатын? / Which resource is renewable? / Какой ресурс является возобновляемым?

A) Мұнай / Oil / Нефть

B) Көмір / Coal / Уголь

C) Биомасса / Biomass / Биомасса

D) Газ / Gas / Газ

8. Энергия тиімділігі дегеніміз не? / What is energy efficiency? / Что такое энергоэффективность?

A) Жоғары температура қолдану / Using high temperature / Использование высокой температуры

B) Минималды энергия қолдану / Using minimal energy / Использование минимальной энергии

C) Ұзақ қыздыру / Long heating / Длительный нагрев

D) Қысымды арттыру / Increasing pressure / Повышение давления

9. Қауіпті химикаттарды азайту не үшін керек? / Why is it important to reduce hazardous chemicals? / Почему важно снижать использование опасных химикатов?

A) Бағаны арттыру / Increase cost / Повышение стоимости

B) Қауіпсіздік үшін / For safety / Для безопасности

C) Өнімді көбейту / Increase production / Увеличение продукции

D) Уақытты ұзарту / Extend time / Увеличение времени

10. Жасыл химия қайда қолданылады? / Where is green chemistry applied? / Где применяется зелёная химия?

A) Тек мектепте / Only in school / Только в школе

B) Тек өндірісте / Only in industry / Только в промышленности

C) Барлық салаларда / In all fields / Во всех сферах

D) Тек зертханада / Only in laboratory / Только в лаборатории

Appendix D

Laboratory Work 1

Topic: Producing Bioplastic from Household Materials

Aim: To produce bioplastic using safe household materials and observe its properties.

Materials and Equipment

Materials	Amount
Starch	1 tablespoon
Water	4 tablespoons
Vinegar	1 teaspoon
Glycerin	1 teaspoon
Small pan or bowl	1
Spoon	1
Baking paper / foil	1 sheet

If glycerin is unavailable at home, it can be purchased at a pharmacy. It makes the bioplastic softer and more flexible.

Theoretical Background

Bioplastic is a material made from natural resources that is less harmful to the environment than conventional plastic. In this experiment, starch is used as the main polymer. Water helps dissolve the starch, vinegar stabilizes the structure, and glycerin improves flexibility.

Procedure

1. Place **1 tablespoon of starch** into a small container.
2. Add **4 tablespoons of water** and mix thoroughly.
3. Add **1 teaspoon of vinegar** to the mixture.
4. Then add **1 teaspoon of glycerin**.
5. Stir the mixture until it becomes smooth.
6. Heat the mixture over low heat while stirring continuously.
7. Continue heating until the mixture thickens and becomes slightly transparent.
8. Pour the prepared mixture onto baking paper or foil and spread it thinly.
9. Leave it to dry for **24–48 hours**.
10. After drying, observe the flexibility, hardness, and strength of the bioplastic.

Safety Rules

Be careful when heating the mixture.

Do not touch hot equipment directly.

It is recommended to perform the experiment under adult supervision.

Do not taste or eat the mixture.

Observation Results

Observation Criteria	Result
Color	Whitish or transparent
Texture	Soft / flexible
Smell	Slight vinegar smell
Final condition after drying	Thin bioplastic film

Conclusion

As a result of this experiment, a simple starch-based bioplastic was successfully produced. Glycerin increased the flexibility of the bioplastic, while vinegar improved the stability of the mixture. This type of bioplastic is made from natural materials and can be effectively used to demonstrate green chemistry principles in environmental and chemistry education.

Laboratory Work 2

Topic: Producing an Eco-Friendly Vase from Fruit Peels

Aim: To create an environmentally friendly decorative vase using fruit peels and natural household materials while demonstrating the principles of recycling and sustainable resource use.

Materials and Equipment

Materials	Amount
Orange, banana, or other fruit peels	Several pieces
Flour	2 tablespoons
Water	3–4 tablespoons
Salt	1 teaspoon
Glue (optional)	Small amount
Bowl	1
Spoon	1

Mold or plastic cup	1
Baking paper	1 sheet

Theoretical Background

Fruit peels are organic waste materials that are usually discarded. However, they can be reused to create biodegradable products. In this experiment, fruit peels are combined with a simple natural paste to produce a small eco-friendly vase. This activity demonstrates recycling, waste reduction, and sustainable design concepts related to green chemistry.

Procedure

1. Wash and dry the fruit peels thoroughly.
2. Cut the peels into small pieces.
3. In a bowl, mix **2 tablespoons of flour**, **1 teaspoon of salt**, and **3–4 tablespoons of water** to form a thick paste.
4. Add a small amount of glue if stronger structure is needed.
5. Mix the fruit peel pieces into the paste.
6. Cover the outside of a plastic cup or mold with the mixture to create the shape of a vase.
7. Press the material firmly to ensure stability.
8. Leave the vase to dry for 24–48 hours in a warm place.
9. After drying, carefully remove the mold.
10. Observe the texture, strength, and appearance of the eco-friendly vase.

Safety Rules

- Wash hands before and after the activity.
- Be careful when using scissors or sharp tools.
- Do not eat the materials during the experiment.
- Keep the working area clean.

Observation Results

Observation Criteria	Result
Color	Natural fruit peel color
Texture	Rough but solid
Smell	Slight natural fruit smell

Final product	Small biodegradable vase

Conclusion

In this experiment, an eco-friendly vase was successfully produced from fruit peels and natural materials. The activity demonstrated how organic waste can be reused creatively instead of being discarded. This experiment supports green chemistry principles by promoting recycling, sustainability, and environmentally responsible practices.

Appendix E

ANNUAL THEMATIC PLAN

Subject: Chemistry | Grade 10 (Social Sciences & Humanities) | 68 hours | 2 lessons per week

Green chemistry content integrated across all quarters (6 additional hours)

Legend: ★ NEW — green chemistry lesson (shaded green) | [reduced] — lesson count reduced to accommodate green chemistry content

Long-term Plan Section	Topic / Content	Learning Objectives	Hrs	Time line	Home work	Notes
QUARTER 1						
10.1A Atomic Structure (5 h)						
10.1A Atomic Structure (5 h)	Modern atomic theory. Electronic states and motion in the atom. Demonstration #1 "Models of Atomic Structure"	10.1.2.1 Know the modern theory of atomic structure; 10.1.2.2 Distinguish between the shapes of s, p, d, f orbitals	1			
	Quantum numbers. Pauli exclusion principle, Hund's rule, Klechkovsky's rule	10.1.3.1 Know the characteristics and values of quantum numbers; 10.1.3.2 Apply the Aufbau principle, Pauli principle, and Hund's rule to explain electron orbital filling; 10.1.3.3 Write electron configurations for the first 36 chemical elements	2			
	Isotopes. Problem-solving: Deriving chemical formulas from the mass fractions of constituent elements	10.1.2.3 Explain the nature of radioactivity and applications of radioactive isotopes; 10.1.1.1 Derive chemical formulas from the mass fractions of constituent elements	1			
	Radioactive substances, nuclear reactions, and their role in Kazakhstan's energy potential	10.2.1.8 Know the concept of radioactive substance; 10.2.1.9 Know types of radioactive decay and write equations for simple nuclear reactions (α, β^-, β^+, γ); 10.2.1.10 Understand the significance of nuclear reactions for Kazakhstan's energy sector	1			
10.1B Periodic Law and Periodic System of Chemical Elements (4 h)						
10.1B Periodic Law and	Periodic law and periodic system in light of atomic structure theory. Valence and oxidation states.	10.2.1.1 Explain the physical meaning of the periodic law; 10.2.1.2 Explain the concepts of valence and oxidation state;	2			

Periodic System (4 h)	Periodicity of elemental properties in main subgroups and periods	10.2.1.3 Describe trends in atomic properties: atomic radius, ionisation energy, electron affinity, electronegativity, and oxidation state				
	Trends in acid-base properties of compounds in periods and groups	10.2.1.4 Explain trends in acid-base properties of oxides, hydroxides, and hydrogen compounds across periods and groups	1			
	Significance of the periodic law for science, technology, and understanding of the chemical world	10.2.1.5 Predict properties of elements and their compounds based on periodic system position; 10.2.1.6 List key directions of scientific development linked to the discovery of the periodic law	1			
10.1C Chemical Bond and Molecular Structure (5 h) [reduced from 6 h]						
10.1C Chemical Bond and Molecular Structure (5 h)	Unified electronic nature of chemical bonds. Covalent bond: exchange and donor-acceptor mechanisms. Properties of covalent bonds. Demonstration #2 "Crystal lattice models of graphite, diamond, CO_2"	10.1.4.1 Explain covalent bond formation by exchange and donor-acceptor mechanisms; 10.1.4.2 Describe properties of the covalent bond; 10.1.4.3 Construct Lewis diagrams for H_2, Cl_2, O_2, N_2, HCl, NH_3	2			
	Hybridisation of atomic orbitals (sp, sp^2, sp^3) and molecular geometry	10.1.4.4 Explain the differences between types of hybridisation; 10.1.4.5 Explain the dependence of substance properties on electronic and spatial structure of molecules (BF_3, CH_4, NH_3, H_2O, $BeCl_2$)	1			
	Electronegativity and bond polarity	10.1.4.6 Explain the physical meaning of electronegativity and predict bond type on its basis	1			
	Ionic and metallic bonds and crystal lattices. Hydrogen bonds. Dependence of substance properties on bond type and crystal lattice. Demonstration #3 "Crystal lattice models of NaCl and copper" Laboratory work #1 "Modelling molecules with different bond types; studying properties of substances with different crystal lattices"	10.1.4.7 Understand that ionic bonds form via electrostatic attraction of oppositely charged ions; 10.1.4.8 Construct Lewis diagrams for NaCl, CaO, MgF_2, KH; 10.1.4.9 Explain metallic bonds and their effect on physical properties of metals; 10.1.4.10 Understand the mechanism of hydrogen bond formation; 10.1.4.11 Predict properties of compounds with various bond types and crystal lattice types	1			

10.1D Introduction to Green Chemistry (1 h) [NEW]						
10.1D Introduction to Green Chemistry (1 h) ★ NEW	History and goals of green chemistry. The 12 Principles of Green Chemistry (Anastas & Warner). Connections between atomic structure, chemical bonding, and the design of safer, more sustainable chemical substances. Discussion: What makes a chemical process "green"?	10.GC.1.1 Understand the concept and historical development of green chemistry; 10.GC.1.2 List and explain the 12 principles of green chemistry; 10.GC.1.3 Identify connections between fundamental chemical knowledge (atomic structure, bonding) and the design of environmentally safe substances and processes	**1**			🌿 Green Chemistry
	Summative Assessment — Quarter 1		**1**			
QUARTER 2						
10.2A Patterns of Chemical Reactions (8 h) [reduced from 9 h]						
10.2A Patterns of Chemical Reactions (8 h)	Classification of chemical reactions. Oxidation-reduction reactions (OVR) involving simple, binary, and complex inorganic substances	10.2.1.7 Classify chemical reactions by direction, number/composition of reactants and products, and by change in oxidation state; 10.2.3.1 Determine oxidation states of elements from compound formulas; 10.2.3.2 Write oxidation and reduction half-equations using the electron balance method	2			
	Electrolysis of salt melts and solutions. Demonstration #4 "Video: industrial electrolysis — production of Cu, Al, Cl_2, and NaOH"	10.2.3.3 Study and explain processes occurring when electric current passes through electrolyte solutions and melts; 10.2.3.4 Predict electrolysis products at electrodes; 10.2.3.5 Write electrolysis schemes for melts and solutions; 10.2.3.6 Calculate mass and volume of electrolysis products	2			
	pH of acid, alkali, and salt solutions. Hydrolysis of salts. Laboratory work #2 "Study of properties of acids, hydroxides, and salts. Hydrolysis of salts" Laboratory work #3 "Experimental confirmation of qualitative composition of acids, bases, and salts; pH of solutions"	10.3.4.1 Prove the qualitative composition of solutions by pH values; 10.3.4.2 Predict the pH environment of a salt solution based on its composition	2			
	Thermal effect of chemical reactions and its significance.	10.3.1.1 Classify chemical reactions by thermal effect;	2			

	Demonstration #5 "Exothermic and endothermic reactions"	10.3.1.2 Explain the significance of the thermal effect; 10.3.1.3 Calculate the thermal effect of a chemical reaction				
10.2B Chemical Kinetics (3 h) [reduced from 4 h]						
10.2B Chemical Kinetics (3 h)	Reaction rate. Factors affecting reaction rate. Laboratory work #4 "Study of the dependence of reaction rate on temperature, concentration, and pressure"	10.3.2.1 Experimentally study the effect of temperature, concentration, and pressure on reaction rate; 10.3.2.2 Explain the effect of various factors on reaction rate; 10.3.2.3 Calculate changes in reaction rate with changes in concentration and temperature	2			
	Catalysts and inhibitors. Homogeneous and heterogeneous catalysis. Laboratory work #5 "Homogeneous and heterogeneous catalysis". Development of catalytic chemistry in Kazakhstan	10.3.2.4 Explain the effect of catalysts and inhibitors on reaction rate; 10.3.2.5 Explain the mechanism of homogeneous and heterogeneous catalysis; 10.3.2.6 Know the development of catalytic chemistry in Kazakhstan	1			
10.2C Chemical Equilibrium (2 h)						
10.2C Chemical Equilibrium (2 h)	Chemical equilibrium and conditions for its shift. Le Chatelier–Braun principle. Laboratory work #6 "Shift of chemical equilibrium (NH_4SCN / $FeCl_3$ system by concentration change)"	10.3.3.1 Experimentally study the effect of various factors on equilibrium shift; 10.3.3.2 Predict the effect of changes in temperature, concentration, and pressure on equilibrium; 10.3.3.3 Write equilibrium constant expressions	2			
10.2D Green Chemistry in Chemical Processes (2 h) [NEW]						
10.2D Green Chemistry in Chemical Processes (2 h) ★ NEW	Atom economy and waste prevention in chemical reactions. Calculating atom economy for industrial reactions (aspirin synthesis, Haber process). Selection of environmentally safe solvents and auxiliary substances.	10.GC.2.1 Calculate atom economy for chemical reactions and evaluate process efficiency; 10.GC.2.2 Apply principles of waste prevention and atom economy to reaction design; 10.GC.2.3 Compare and evaluate solvents and reagents based on environmental and safety criteria	**1**			🌿 Green Chemistry
	Energy efficiency in chemical reactions. The role of catalysis in green chemistry.	10.GC.2.4 Explain how catalysis contributes to energy efficiency and waste reduction;	**1**			🌿 Green Chemistry

	Connection between Le Chatelier's principle and optimisation of sustainable industrial processes. Case study: Green catalytic processes in Kazakhstan's chemical industry.	10.GC.2.5 Connect knowledge of kinetics and equilibrium to the design of low-waste processes; 10.GC.2.6 Analyse real-world examples of green catalytic processes and evaluate their sustainability				
	Summative Assessment — Quarter 2		**1**			
QUARTER 3						
10.3A General Characteristics of Metals and Non-metals (5 h) [reduced from 6 h]						
10.3A General Characteristics of Metals and Non-metals (5 h)	Metals and non-metals: chemical elements and simple substances. Features of atomic/ionic structure and crystal lattices; property trends in periods and groups. Demonstration #6 "Samples of metals, non-metals, and their compounds; crystal lattice models"	10.2.1.11 Describe structural features of metals and non-metals: atomic radius, ionisation energy, electron affinity, crystal lattice types; 10.2.1.12 Predict property trends for metals and non-metals in periods and groups	2			
	Physical and chemical properties of metals and non-metals. Electrochemical series of metal activity. Laboratory work #7 "Chemical properties of typical metals, non-metals, and amphoteric elements"	10.2.1.13 Explain the main physical properties of metals and non-metals; 10.2.1.14 Understand the principle of arrangement of metals in the electrochemical series; 10.2.1.15 Write equations characterising chemical properties of metals and non-metals; 10.2.1.16 Experimentally investigate properties of typical metals, non-metals, and amphoteric elements	2			
	Distribution of metals and non-metals in nature. Biological role of metals and non-metals in living organisms. Environmental impact of selected metals and non-metals [combined lesson]	10.2.1.17 Know the distribution of metals, non-metals, and their compounds in nature; 10.4.1.1 Study the environmental impact of selected metals and non-metals; 10.4.1.2 Explain the biological role of metals and non-metals in living organisms	1			
10.3B Key s-Block Elements and Their Compounds (5 h) [reduced from 6 h]						
10.3B Key s-Block Elements and Their Compounds (5 h)	Position of s-elements in the periodic system; features of atomic structure; comparison of metallic and reducing properties	10.2.1.18 Explain the general properties of s-elements based on their atomic structure; 10.2.1.19 Compare the metallic and reducing properties of s-elements and write reaction equations	1			

	Sodium, potassium, and their key compounds: physical and chemical properties, production, applications, and biological role. Demonstration #7 "Reactions of Na, K, Ca with water; flame tests for Na^+, K^+, Ca^{2+} ions"	10.2.1.20 Know methods for producing sodium, potassium, and their key compounds; 10.2.1.21 Explain differences in chemical activity of Na, K, and Ca in reactions with water; 10.4.1.3 Explain the biological role of sodium and potassium compounds	2			
	Calcium, magnesium, and their key compounds. Water hardness and methods of removal. Natural compounds of alkali and alkaline earth metals in Kazakhstan. [combined lesson] Laboratory work #8 "Samples of key Na, K, Mg, Ca salts; comparison of metal activity; flame tests"	10.2.1.22 Write equations for the properties of Ca, Mg, and their compounds; 10.2.1.23 Carry out qualitative reactions for Na^+, K^+, Ca^{2+} ions; 10.4.1.4 Explain the biological role of Ca and Mg compounds; 10.4.1.5 Explain water hardness and methods for its removal; 10.4.1.6 Know natural compounds of alkali and alkaline earth metals in Kazakhstan; 10.2.2.1 Calculate mass and amount of substance from chemical equations (metal compounds)	2			
10.3C Key d-Block Elements and Their Compounds (6 h) [reduced from 7 h]						
10.3C Key d-Block Elements and Their Compounds (6 h)	Position of d-elements in the periodic system; features of atomic structure. Deposits of Cu, Zn, Fe, Cr, and their compounds in Kazakhstan	10.2.1.24 Explain the position of d-elements in the periodic system based on atomic structure; 10.4.1.7 Name deposits of copper, zinc, iron, and chromium in Kazakhstan	1			
	Copper, zinc, and their key compounds. Laboratory work #9 "Qualitative reactions for Cu^{2+} and Zn^{2+} ions"	10.2.1.25 Explain the properties and applications of copper, zinc, and their key compounds; 10.2.1.26 Identify Cu^{2+} and Zn^{2+} ions	1			
	Chromium and its compounds	10.2.1.27 Explain the properties and applications of chromium and its compounds	1			
	Iron and its compounds. Laboratory work #10 "Qualitative reactions for Fe^{2+} and Fe^{3+} ions"	10.2.1.28 Describe the physical and chemical properties and production of iron and its compounds; 10.2.1.29 Identify Fe^{2+} and Fe^{3+} ions	1			
	Practical work #1 "Preparation of Fe(II) and Fe(III) hydroxides,	10.2.1.30 Experimentally prepare hydroxides of Fe(II), Fe(III), Cu(II), Zn,	1			

	Cu(II), Zn, Cr(III) hydroxides; testing with acids and bases"	and Cr(III) and study their interactions with acids and bases				
	Types of corrosion and corrosion prevention. Calculations for reactions of metals with impurities; practical yield. Green approaches to corrosion prevention: eco-friendly inhibitors and protective coatings	10.2.3.7 Know types of corrosion, their causes, and their negative effects on metal structures; 10.2.2.2 Calculate mass and practical yield from equations involving metals with impurities; 10.4.1.7a Identify environmentally preferable strategies for corrosion prevention	1			
10.3D Green Chemistry and Metals: Sustainable Resource Management (1 h) [NEW]						
10.3D Green Chemistry and Metals: Sustainable Resource Management (1 h) ★ NEW	Environmental impact of metal mining, extraction, and metallurgical processing. Recycling and circular economy principles applied to metals. Sustainable resource management in Kazakhstan's mining and metallurgical industry. Case study: Green approaches to copper and iron recycling in Kazakhstan.	10.GC.3.1 Analyse the environmental impact of metal extraction and metallurgical processing; 10.GC.3.2 Explain the concept of circular economy and its application to metal resource management; 10.GC.3.3 Propose green chemistry approaches to metal recovery and recycling; 10.GC.3.4 Evaluate Kazakhstan's mining and metallurgical industry from a sustainability perspective	**1**			🌿 Green Chemistry
	Summative Assessment — Quarter 3		**1**			
QUARTER 4						
10.4A Key p-Block Elements and Their Compounds (10 h) [reduced from 11 h]						
10.4A Key p-Block Elements and Their Compounds (10 h)	Position of p-elements in the periodic system; features of atomic structure. Aluminium and its compounds	10.2.1.31 Explain trends in properties of p-elements and their compounds in groups and periods; 10.2.1.32 Study the amphoteric properties of aluminium oxide and hydroxide; 10.2.1.33 Describe applications of aluminium and its alloys	1			
	Carbon, silicon, and their key compounds. Distribution in nature. Demonstration #8 "Adsorption of dissolved substances by activated carbon"	10.2.1.34 Study the physical and chemical properties of carbon, silicon, and their compounds; 10.2.1.35 Explain carbon monoxide poisoning and describe first aid measures	2			
	Structure and properties of the nitrogen molecule. Ammonia, ammonium salts. Orthophosphoric	10.2.1.36 Explain the low chemical activity of N_2 based on molecular structure;	2			

	acid and phosphates. Applications as fertilisers. Environmental impact of NO_x, nitrates, and phosphates. Practical work #2 "Preparation of ammonia; study of its aqueous solution and ammonium salts"	10.2.1.37 Write equations for production and properties of NH_3 and its aqueous solution; 10.4.1.8 Analyse the impact of NO_x on the atmosphere and nitrates on soil and water; 10.4.1.9 Propose solutions to reduce the environmental impact of N and P compounds; 10.2.1.38 Study the physical and chemical properties of H_3PO_4 and phosphates				
	Sulfur, its oxides and acids, sulfates and their properties. Role of SO_2 in acid rain formation. Environmental impact of sulfur-containing fossil fuels.	10.2.1.39 Describe the formation of SO_2 during combustion of sulfur-containing fuels; 10.4.1.10 Explain the role of SO_2 in acid rain formation and its environmental impact; 10.2.1.40 Compare properties of dilute and concentrated sulfuric acid; 10.4.1.11 Explain the use of SO_2 in food preservation	1			
	Halogens. Hydrogen chloride, hydrochloric acid, and chlorides. Biological role of iodine. Health protection measures for iodine deficiency in Kazakhstan	10.2.1.41 Explain trends in physical and chemical properties of halogens within the group; 10.2.1.42 Study the chemical properties of HCl and know its applications; 10.4.1.12 Know the biological role of iodine and explain iodine-deficiency diseases in Kazakhstan; propose solutions	2			
	Practical work #3 "Qualitative reactions for selected anions"	10.2.1.43 Know qualitative reactions for Cl^-, Br^-, I^-, SO_4^{2-}, CO_3^{2-}, PO_4^{3-}, NO_3^-, SiO_3^{2-} ions; 10.2.1.44 Plan and carry out an experiment to identify anions	2			
10.4B Production of Inorganic Compounds and Alloys (4 h) [reduced from 6 h]						
10.4B Production of Inorganic Compounds and Alloys (4 h)	Production of ferrous and non-ferrous metals and their alloys in Kazakhstan	10.2.3.8 Know methods for producing metals in industry; 10.2.3.9 Name compositions of key alloys: cast iron, steel, brass, bronze, cupronickel, duralumin;	2			

		10.2.3.10 Describe methods for producing and properties of cast iron and steel; 10.4.1.13 Explain environmental problems of chemical industries in Kazakhstan				
	Industrial production: sulfuric acid (contact process), ammonia (Haber process), and nitric acid. Silicate industry in Kazakhstan [combined lesson]	10.2.1.45 Describe the contact process for industrial H_2SO_4 production and its industrial significance; 10.2.1.46 Describe industrial production of NH_3 and HNO_3 and applications of their products; 10.2.3.11 Describe the production of glass and cement and their applications	1			
	Environmental pollution from chemical and metallurgical production waste. Assessment of environmental impact [combined lesson]	10.4.1.14 Evaluate the impact of chemical and metallurgical production waste on the environment	1			
10.4C Green Industrial Chemistry and Sustainable Production in Kazakhstan (2 h) [NEW]						
10.4C Green Industrial Chemistry and Sustainable Production (2 h) ★ NEW	Green chemistry approaches to industrial chemical processes: redesigning the contact process (H_2SO_4), Haber process (NH_3), and metal smelting. Comparative analysis: conventional vs. green industrial chemistry. Laboratory practical: Synthesis of bioplastic from natural starch as an example of green polymer chemistry.	10.GC.4.1 Evaluate conventional industrial processes (contact process, Haber process, metal smelting) from a green chemistry perspective; 10.GC.4.2 Propose modifications to industrial processes to reduce energy consumption, waste, and environmental impact; 10.GC.4.3 Carry out a laboratory synthesis of bioplastic as a practical example of green chemistry principles	**1**			🌿 Green Chemistry
	Sustainable development and green chemistry in Kazakhstan: current state, challenges, and prospects. Student mini-presentations: "A Greener Kazakhstan — applying green chemistry to address local environmental challenges." Reflection: connecting the 12 principles of green chemistry to all topics studied throughout the year.	10.GC.4.4 Analyse the current state of green chemistry implementation in Kazakhstan's chemical industry; 10.GC.4.5 Connect the 12 principles of green chemistry to the chemistry topics studied throughout the year; 10.GC.4.6 Develop and present proposals for applying green chemistry to address specific environmental challenges in Kazakhstan	**1**			🌿 Green Chemistry
	Summative Assessment — Quarter 4		**1**			

References for the Integrated Green Chemistry Content

The peer-reviewed and institutional sources below are the authoritative origins of the green chemistry concepts, metrics, and frameworks integrated into this plan. Each is keyed to the in-table "Source:" notes added to the green chemistry lessons.

American Chemical Society. (n.d.). 12 principles of green chemistry. Retrieved June 9, 2026, from https://www.acs.org/green-chemistry-sustainability/principles/12-principles-of-green-chemistry.html

Anastas, P. T., & Warner, J. C. (1998). Green chemistry: Theory and practice. Oxford University Press.

OECD. (2021). Resource efficiency, the circular economy, sustainable materials management and trade in metals and minerals. OECD Publishing.

Raabe, D. (2023). The materials science behind sustainable metals and alloys. Chemical Reviews, 123(5), 2436-2608. https://doi.org/10.1021/acs.chemrev.2c00799

Sheldon, R. A. (2007). The E factor: Fifteen years on. Green Chemistry, 9(12), 1273–1283. https://doi.org/10.1039/B713736M

Sheldon, R. A., Arends, I., & Hanefeld, U. (2007). Green chemistry and catalysis. Wiley-VCH.

Trost, B. M. (1991). The atom economy-A search for synthetic efficiency. Science, 254(5037), 1471–1477. https://doi.org/10.1126/science.1962206

Note. Kazakhstan-specific elements - named mineral deposits, the starch-bioplastic laboratory protocol, and national case studies on green/sustainable industry - should be cited from your own national curriculum documents, laboratory manuals, and local literature. They have deliberately not been assigned references here to avoid fabricated citations.

Appendix F

ANNUAL THEMATIC PLAN

Subject: Chemistry | Grade 11 (Social Sciences & Humanities) | 68 hours | 2 lessons per week

Green chemistry content integrated across all quarters (6 additional hours)

Green-chemistry topics are distinct from those in the Grade 10 plan; together the two grades cover the 12 principles without repetition.

Legend: ★ NEW — green chemistry lesson (shaded green) | [reduced] — lesson count reduced to accommodate green chemistry content

Long-term Plan Section	Topic / Content	Learning Objectives	Hrs	Time line	Home work	Notes
QUARTER 1 (16 hours)						
11.1A Introduction to Organic Chemistry. Theory of the Structure of Organic Compounds (7 h)						
11.1A Introduction to Organic Chemistry (7 h)	Features of the carbon atom. Hybridisation. Electronic nature and characteristics of chemical bonds in organic compounds. Demonstration #1 "Samples of organic substances (petroleum, kerosene, ethanol, glycerol, glucose, sucrose, paraffin, cotton, wood)"	Study the hybridisation of carbon in hydrocarbons Explain the features of the carbon atom and its ability to form C–C bonds	**1**			
	Main postulates of A. M. Butlerov's theory of the structure of organic compounds. Isomerism and the homologous series	Know the main postulates of Butlerov's theory Distinguish empirical, molecular, structural, and spatial formulae of hydrocarbons Name types of isomerism and write formulae of structural, positional, functional-group, and inter-class isomers	**2**			
	Concept of free radicals and their significance in the life of living organisms	Form an understanding of the structure of free radicals Know the role of radicals in the life of living organisms	**1**			
	Classification and nomenclature of organic substances. Laboratory work #1 "Ball-and-stick models of methane, ethane, ethylene, acetylene, benzene, methanol, ethanol, and acetic acid molecules"	Understand the formation of homologous series Explain similarities and differences in properties of homologues Construct structural formulae and name compounds by IUPAC nomenclature	**2**			

	Significance of organic compounds in nature and human life. The role of Kazakhstani scientists in the development of organic chemistry	Understand the significance of organic compounds in human life Understand the contribution of Kazakhstani scientists to organic chemistry	**1**			
11.1B Hydrocarbons and Their Natural Sources (7 h) [reduced from 8 h]						
11.1B Hydrocarbons and Their Natural Sources (7 h)	Alkanes. Demonstration #2 "Combustion of methane, ethylene, acetylene; samples of natural and synthetic rubber, vulcanised rubber, ebonite" [reduced from 3 h]	Investigate the combustion of alkanes and explain their use as fuels Know the combustion products of alkanes and assess their environmental impact Determine a molecular formula from combustion-product data Find empirical and molecular formulae from mass fractions and vapour density	**2**			
	Cycloalkanes	Examine the homologous series, structure, and physical and chemical properties of cycloalkanes Write formulae of isomers and name substances by IUPAC	**1**			
	Alkenes. Polyethylene. Rubber. Laboratory work #2 "Reaction of ethylene, acetylene, a petroleum sample, and benzene with potassium permanganate solution and bromine water / iodine"	Examine the homologous series, structure, properties, and preparation of unsaturated hydrocarbons Write polymerisation reactions (polyethylene, polypropylene, polyvinyl chloride)	**2**			
	Practical work #1: "Preparation and study of the properties of ethylene"	Prepare ethylene from ethanol and study its physical and chemical properties Know the qualitative reactions for alkenes (unsaturation)	**2**			
11.1C Green Chemistry and Renewable Carbon Feedstocks (1 h) [NEW]						
11.1C Green Chemistry and Renewable Carbon Feedstocks (1 h) ★ NEW	Renewable (biomass) versus fossil (petroleum, natural gas, coal) feedstocks for organic chemistry. Principle 7 of green chemistry — the use of renewable feedstocks. Relationship between hydrocarbon structure and the choice of sustainable raw materials. Discussion: moving organic synthesis beyond petroleum.	11.GC.1.1 Distinguish between renewable (biomass) and non-renewable (fossil) feedstocks for organic synthesis 11.GC.1.2 Relate Principle 7 of green chemistry (use of renewable feedstocks) to the production of organic compounds 11.GC.1.3 Evaluate the sustainability of the carbon sources used by the chemical industry	**1**			🌿 **Green Chemistry**

Summative Assessment — Quarter 1			**1**			
QUARTER 2 (16 hours)						
11.2A Hydrocarbons and Their Natural Sources (continued) (14 h) [reduced from 15 h]						
11.2A Hydrocarbons and Their Natural Sources (14 h)	Alkadienes. Laboratory work #3 "Constructing ball-and-stick models of isoprene rubber"	Know the structure and properties of alkadienes Explain the properties of alkadienes from their structure Build ball-and-stick models of diene (isoprene) polymerisation products	**2**			
	Alkynes	Examine the homologous series, structure, physical and chemical properties, and preparation of alkynes	**3**			
	Arenes and their derivatives [reduced from 4 h]	Explain the structure of the benzene molecule from the standpoint of electron delocalisation Write reactions for the preparation of benzene and its homologues Describe properties characteristic of benzene and its homologues Know the use of benzene in organic synthesis	**3**			
	Genetic relationship of hydrocarbons and their derivatives	Construct a scheme of the genetic relationship of the main classes of organic compounds Calculate the yield and the amount (volume, mass) of a reaction product from the amount of reagent	**2**			
	Natural sources of hydrocarbons and their deposits in Kazakhstan. Processing of gas, oil, and coal. Development of the oil-and-gas and coal industries in Kazakhstan. Environmental aspects of extraction and processing in Kazakhstan	Know that carbon-containing compounds can be used as fuels Locate coal, oil, and natural-gas deposits in Kazakhstan on a map Describe extraction and understand the significance of crude-oil distillation Know the applications of crude-oil distillation products Understand that fossil-fuel reserves are limited Know that burning hydrocarbon fuels pollutes the environment and affects the climate	**4**			
11.2B Greener Fuels and the Carbon Footprint of Hydrocarbons (1 h) [NEW]						

11.2B Greener Fuels and the Carbon Footprint of Hydrocarbons (1 h) ★ NEW	Environmental cost of fossil hydrocarbon fuels. Biofuels (bioethanol, biodiesel) as renewable alternatives. Carbon footprint and life-cycle thinking applied to organic fuels. Case study: prospects for biofuels and the reduction of associated-gas flaring in Kazakhstan's energy sector.	11.GC.2.1 Compare the environmental impact of fossil hydrocarbon fuels and renewable biofuels 11.GC.2.2 Explain the production and the advantages and limitations of bioethanol and biodiesel 11.GC.2.3 Apply life-cycle and carbon-footprint thinking to evaluate organic fuels	**1**			🌿 **Green Chemistry**
Summative Assessment — Quarter 2			**1**			
QUARTER 3 (20 hours)						
11.3A Oxygen-Containing Organic Compounds (17 h) [reduced from 19 h]						
11.3A Oxygen-Containing Organic Compounds (17 h)	Classification and nomenclature of oxygen-containing organic compounds	Describe the structure of the functional groups of alcohols, aldehydes, ketones, carboxylic acids, and esters Construct structural formulae of alcohols, aldehydes, ketones, carboxylic acids, and esters and name them by IUPAC	**2**			
	Alcohols: monohydric and polyhydric. Phenols. Laboratory work #4 "Preparation of ethanol by hydration of ethylene and by fermentation of glucose". Laboratory work #5 "Solubility and combustion of alcohols; qualitative reactions for monohydric and polyhydric alcohols"	Classify and write structural, functional-group, and inter-class isomers of alcohols Know methods of preparing alcohols and phenols Write equations for the chemical properties of alcohols and phenols Name the applications of alcohols and phenols Study the toxic effects of alcohols on the human body	**4**			
	Aldehydes. Ketones. Carboxylic acids. Practical work #2 "Qualitative reactions for oxygen-containing organic substances" [reduced from 6 h]	Construct structural formulae of aldehydes and ketones and name them by IUPAC Write equations for the preparation of aldehydes and ketones Experimentally distinguish aldehydes and ketones Name the oxidation and reduction products of aldehydes and ketones Explain the properties and preparation of carboxylic acids and write equations for their chemical properties	**5**			

	Esters: simple and complex. Fats. Soaps and detergents. Production of soap and synthetic detergents in Kazakhstan. Demonstration #3 "Testing soap and washing-powder solutions with indicators" [reduced from 4 h]	Write equations for the preparation of ethers and esters Know the composition and structure of fats Understand the functions of fats and carry out a qualitative reaction for fats Name the products of hydrolysis and saponification of fats Name the applications of carboxylic acids, esters, soap, and synthetic detergents Understand the need to protect nature from pollution by synthetic detergents	**3**			
	Carbohydrates. Classification. Biological role. Monosaccharides (glucose, fructose). Disaccharides (sucrose, lactose). Polysaccharides (starch, cellulose). Laboratory work #6 "Detection of starch in food products"	Distinguish the molecular formulae of glucose, fructose, ribose, deoxyribose, sucrose, starch, and cellulose Experimentally detect functional groups in glucose Write equations for alcoholic and lactic-acid fermentation of glucose Carry out a qualitative reaction for starch Name the hydrolysis products of sucrose, starch, and cellulose Compare the structure and properties of starch and cellulose	**3**			
11.3B Green Organic Synthesis: Safer Solvents and Biocatalysis (2 h) [NEW]						
11.3B Green Organic Synthesis (2 h) ★ NEW	Green solvents in organic synthesis: water, supercritical CO_2, and bio-based and ionic-liquid solvents as replacements for hazardous organic solvents (Principle 5 — safer solvents and auxiliaries). Biodegradable surfactants as environmentally preferable alternatives to conventional synthetic detergents.	11.GC.3.1 Identify green solvents (water, supercritical CO_2, bio-based / ionic-liquid solvents) and justify replacing hazardous organic solvents 11.GC.3.2 Explain why biodegradable surfactants are environmentally preferable to conventional synthetic detergents	**1**			🌿 **Green Chemistry**
	Biocatalysis and enzymatic synthesis as a green route to alcohols, carboxylic acids, and esters (fermentation, enzyme catalysis). Advantages of	11.GC.3.3 Explain the principles and advantages of biocatalysis and enzymatic synthesis of oxygen-containing organic compounds	**1**			🌿 **Green Chemistry**

	biocatalysis: mild conditions, high selectivity, reduced waste. Case study: green fermentation routes to organic acids.	11.GC.3.4 Compare conventional and biocatalytic / fermentative routes to alcohols, acids, and esters against green-chemistry criteria				
Summative Assessment — Quarter 3			**1**			
QUARTER 4 (16 hours)						
11.4A Nitrogen-Containing and Heterocyclic Compounds. Nucleic Acids (8 h)						
11.4A Nitrogen-Containing Compounds. Nucleic Acids (8 h)	Amines. Aniline	Know the classification and nomenclature of amines Compare the structures and basic properties of ammonia, amines, and aniline Explain the physical properties of amines and aniline and write equations for their preparation	**2**			
	Amino acids. Demonstration #4 "Confirmation of functional groups in amino acids"	Know trivial and systematic names of amino acids Describe the composition and structure of amino-acid molecules Examine the amphoteric nature of amino acids	**2**			
	Proteins. Demonstration #5 "Dissolution, precipitation, and denaturation of proteins; combustion of proteins (wool or feathers)". Laboratory work #7 "Colour reactions of proteins"	Explain the formation of peptide bonds in proteins from α-amino acids Know the hydrolysis products and functions of proteins Know protein denaturation and qualitative reactions for proteins	**2**			
	Nucleic acids. Demonstration #6 "Models of DNA and RNA molecules"	Know the general concept and classification of nucleic acids Compare the structures of DNA and RNA Explain the biological role of DNA and RNA and understand the significance of genetic engineering and biotechnology	**2**			
11.4B Artificial and Synthetic Polymers. Chemistry in Human Life (5 h) [reduced from 7 h]						
11.4B Artificial and Synthetic Polymers. Chemistry in Life (5 h)	Artificial and synthetic polymers: plastics, rubbers, fibres. Polymer production in Kazakhstan. Demonstration #7 "Samples of plastics, synthetic rubbers, and fibres". Laboratory work #8	Distinguish the concepts of monomer, repeating unit, oligomer, polymer, and degree of polymerisation Write polymerisation and polycondensation reactions Name the properties and applications of selected polymers and plastics	**2**			

	"Identification of plastics and fibres" [reduced from 3 h]	Experimentally identify plastics and fibres Know the types of polymers produced in Kazakhstan				
	Concept of vitamins and hormones. The role of biogenic organic substances	Describe the functions of vitamins and hormones in the human body Know the natural sources of selected vitamins	**2**			
	Chemistry and life. Environmental problems [reduced from 2 h]	Name and explain the 12 principles of green chemistry Know the sources of pollution of the atmosphere, hydrosphere, and lithosphere and propose solutions Explain the difference between the greenhouse effect and ozone-layer depletion	**1**			
11.4C Sustainable Polymers and Green Chemistry for Life (2 h) [NEW]						
11.4C Sustainable Polymers and Green Chemistry for Life (2 h) ★ NEW	Designing polymers for degradation (Principle 10 — design for degradation). Biodegradable polymers (PLA, PHA, polysaccharide-based) versus persistent synthetic plastics. The microplastics problem. Chemical recycling and depolymerisation of polymers as a green approach to plastic waste.	11.GC.4.1 Explain ‘design for degradation’ and compare biodegradable polymers with persistent synthetic plastics 11.GC.4.2 Describe chemical recycling / depolymerisation as a green approach to plastic waste and explain the problem of microplastics	**1**			🌿 **Green Chemistry**
	Designing safer organic chemicals (Principle 4 — designing safer chemicals; Principle 3 — less hazardous chemical synthesis). Green chemistry and human and environmental health. Reflection connecting the 12 principles to the organic chemistry studied throughout the year. Student mini-presentations: "Green organic chemistry for a sustainable Kazakhstan."	11.GC.4.3 Apply the principles of designing safer chemicals and less hazardous synthesis to organic compounds 11.GC.4.4 Connect the 12 principles of green chemistry to the organic chemistry studied throughout the year and propose green solutions to local environmental challenges	**1**			🌿 **Green Chemistry**
Summative Assessment — Quarter 4			**1**			

References for the Integrated Green Chemistry Content (APA 7th ed.)

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American Chemical Society. (n.d.). 12 principles of green chemistry. Retrieved June 9, 2026, from https://www.acs.org/green-chemistry-sustainability/principles/12-principles-of-green-chemistry.html

Anastas, P. T., & Warner, J. C. (1998). Green chemistry: Theory and practice. Oxford University Press.

Clark, J. H., & Tavener, S. J. (2007). Alternative solvents: Shades of green. Organic Process Research & Development, 11(1), 149–155. https://doi.org/10.1021/op060160g

Naik, S. N., Goud, V. V., Rout, P. K., & Dalai, A. K. (2010). Production of first and second generation biofuels: A comprehensive review. Renewable and Sustainable Energy Reviews, 14(2), 578–597. https://doi.org/10.1016/j.rser.2009.10.003

Rahimi, A., & García, J. M. (2017). Chemical recycling of waste plastics for new materials production. Nature Reviews Chemistry, 1, Article 0046. https://doi.org/10.1038/s41570-017-0046

Sheldon, R. A., & Woodley, J. M. (2018). Role of biocatalysis in sustainable chemistry. Chemical Reviews, 118(2), 801–838. https://doi.org/10.1021/acs.chemrev.7b00203

Tuck, C. O., Pérez, E., Horváth, I. T., Sheldon, R. A., & Poliakoff, M. (2012). Valorization of biomass: Deriving more value from waste. Science, 337(6095), 695–699. https://doi.org/10.1126/science.1218930

Note. Kazakhstan-specific elements — named oil, gas, and coal fields; national case studies on biofuels and green/sustainable industry; and local recycling examples — should be cited from your own national curriculum documents, laboratory manuals, and local literature. They have deliberately not been assigned references here to avoid fabricated citations.

Appendix G

ҚЫСҚА МЕРЗІМДІ ЖОСПАР (КМЖ)

Химия · 11-сынып (ҚГБ) · «Жасыл химия» модулі · 1 сағат (45 мин)

Ұзақ мерзімді жоспар бөлімі:	11.2B Көмірсутектер және олардың табиғи көздері — «Жасыл химия» модулі
Педагогтің аты-жөні:	
Күні:	
Сынып: 11 (ҚГБ)	Қатысқандар саны: _____ Қатыспағандар саны: _____
Сабақтың тақырыбы:	**Жасыл отын: биоотынның экологиялық тиімділігі. Биоэтанол және биодизель**
Оқу бағдарламасына сәйкес оқу мақсаттары:	11.GC.2.1 қазба көмірсутектік отын мен жаңартылатын биоотынның қоршаған ортаға әсерін салыстыру; 11.GC.2.2 биоэтанол мен биодизельдің алынуын, артықшылықтары мен шектеулерін түсіндіру; 11.GC.2.3 органикалық отындарды бағалауда өмірлік цикл мен «көміртек ізі» тұрғысынан ойлауды қолдану.
Сабақтың мақсаты:	**Барлық оқушылар:** қазба отын мен биоотынның айырмашылығын атайды, биоэтанол мен биодизельге мысал келтіреді. **Көптеген оқушылар:** биоэтанолдың алыну реакциясын түсіндіреді, биоотынның артықшылықтары мен шектеулерін салыстырады. **Кейбір оқушылар:** отынның «көміртек ізін» және өмірлік циклін талдап, негізделген баға береді.
Бағалау критерийлері:	• қазба отын мен биоотынды экологиялық белгілері бойынша салыстырады; • биоэтанол мен биодизельдің алынуын сипаттайды; • отынды «көміртек ізі» тұрғысынан бағалайды.
Құндылықтарды дарыту:	«Мәңгілік ел» жалпыұлттық идеясы аясында табиғатқа жанашырлық, тұрақты даму және Қазақстанның жасыл экономикаға көшу құндылықтары.
Пәнаралық байланыс:	Биология (фотосинтез, биомасса, ашыту), география (Қазақстан энергетикасы), экономика (жасыл экономика).
АКТ қолдану дағдылары:	Презентация мен бейнематериалды қабылдау; «көміртек ізі» онлайн-калькуляторымен танысу.
Алдыңғы білім:	Алкандар мен көмірсутектердің жануы, жану өнімдері (CO_2, H_2O), мұнайды өңдеу, парниктік эффект туралы түсінік.

Сабақтың барысы

Сабақтың кезеңі / Уақыт	Педагогтің әрекеті	Оқушының әрекеті	Бағалау / Ресурстар

Сабақтың басы (0–7 мин)	1. Ұйымдастыру: амандасу, ынтымақтастық ахуалын қалыптастыру. 2. Өткенді өзектендіру (сұрақ-жауап): көмірсутек отыны жанғанда не түзіледі? CO_2 атмосфераға қалай әсер етеді? Мұнай қоры жаңартыла ма? 3. Қызығушылықты ояту: «Көлік жанармайын өсімдіктен алуға бола ма?» проблемалық сұрағы, қысқа бейнефрагмент. 4. Сабақтың тақырыбы мен мақсатын бірге тұжырымдау.	Сұрақтарға жауап беріп, өткен білімін еске түсіреді. Проблемалық сұраққа болжам айтады. Сабақ мақсатымен танысады.	Қалыптастырушы бағалау: ауызша кері байланыс, «бас бармақ» әдісі. Ресурстар: слайд, қысқа бейне.
Сабақтың ортасы (7–37 мин)	1. Жаңа материал (мини-дәріс + слайд, 8 мин): • Биомасса — жаңартылатын энергия көзі. • Биоэтанол: қант пен крахмалды ашыту — $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ (E10, E85 қоспалары). • Биодизель: өсімдік/жануар майынан алынатын эфир (май қышқылдарының метил эфирлері). • «Көміртек ізі» және «көміртек бейтараптығы»: жанғанда бөлінген CO_2-ні өсімдік фотосинтезде сіңірген → таза шығарынды аз. • Өмірлік цикл (LCA): өсіру, тасымалдау, өңдеу энергиясын ескеру. 2. Топтық жұмыс (12 мин): қазба отын мен биоотынды критерийлер (CO_2, жаңартылу, қор, шектеулер) бойынша Т-кесте/Венн диаграммасына салыстырып, постермен қорғау. 3. Деңгейлік тапсырма (10 мин): А — отынды «жаңартылатын/жаңартылмайтын» деп жіктеу; В — биоэтанолдың «+/–» кестесі; С — «Биоотын әрқашан жасыл ма?» (1-ші және 2-ші буын) негіздемесі. Қазақстан контексі: ілеспе газды алаулату мәселесі.	Жазып, тыңдап, нақтылаушы сұрақ қояды. Реакция теңдеуін дәптерге түсіреді. Топта ынтымақтасып салыстыру кестесін жасайды, нәтижесін таныстырады. Өз деңгейіне сай тапсырманы орындайды. Қазақстандағы жасыл отын болашағын талқылауға қатысады.	Топтық жұмысты критерий бойынша өзара бағалау. Тапсырманы дескриптор бойынша қалыптастырушы бағалау. Ресурстар: слайд, постер қағазы, маркер, деңгейлік карточкалар.
Сабақтың соңы (37–45 мин)	1. Бекіту — «3-2-1» әдісі: 3 жаңа білген нәрсе, 2 қызықты факт, 1 сұрақ. (5 мин) 2. Рефлексия — «Бағдаршам»: жасыл (түсіндім) / сары (сұрағым бар) / қызыл (қиналдым). (2 мин) 3. Үй тапсырмасы: «Қазақстан үшін қай биоотын перспективалы?» тақырыбында қысқа эссе немесе инфографика. (1 мин)	«3-2-1» парағын толтырады. Бағдаршаммен өзін-өзі бағалайды. Үй тапсырмасын жазып алады.	«3-2-1» арқылы оқу мақсатына жетуді тексеру. Ресурстар: стикер/бағдаршам карточкалары.

Саралау	Бағалау	Денсаулық және қауіпсіздік
• Тапсырмалардың деңгейленуі (A/B/C). • Топта рөлдерді бөлу, қолдау сұрақтары. • Қабілеті жоғары оқушыларға өмірлік цикл талдауы сияқты ашық тапсырма. • Көрнекілік (диаграмма, бейне) арқылы қолдау.	• Ауызша кері байланыс, «бас бармақ». • Топтық жұмысты өзара бағалау. • «3-2-1» және «бағдаршам». • Дескрипторлар: жіктейді — сипаттайды — салыстырады — бағалайды.	• АКТ құралдарымен жұмыс ережелерін сақтау. • Сабақ ортасында қысқа сергіту сәті. • Зертханалық тәжірибе жоспарланбаған.

Сабақ бойынша рефлексия (педагог үшін)
• Оқу мақсаттары шынайы болды ма? Барлық оқушы мақсатқа жетті ме? • Саралау тиімді болды ма? • Уақытты тиімді пайдаландым ба? Жоспардан ауытқу болды ма, неліктен? • Келесі сабақта нені өзгертер едім?

Appendix H

Table 3.1. Summary of participant's pedagogical strategies, illustrative examples, and reported student outcomes, by thematic cluster (N = 15)

Participant (Country)	Pedagogical strategy / approach	Illustrative lesson or activity	Reported student outcome
Inquiry-based and contextualized approaches			
P1 (South Africa)	Socratic questioning; inquiry-based learning	Gibbs free energy taught through environmentally relevant chemical reactions	Improved conceptual understanding
P4 (Indonesia)	Context-based learning grounded in an eco-theological framework	AI-based environmental assignments linking chemistry to community issues	Increased environmental awareness and responsibility
P5 (Indonesia)	Project-based learning within a future-oriented curriculum	Student-designed projects on waste reduction and sustainable lab practice	Enhanced critical thinking and collaboration
P6 (Australia / Indonesia)	Interdisciplinary, context-based instruction	Climate case studies evaluating the impact of chemical industries	Deepened conceptual understanding through contextualization
Technology-enhanced and AI-supported learning			
P2 (South Africa)	AI-supported case-based learning	Student-created case studies on pollution reduction	Increased motivation and engagement
P9 (Jordan)	Adaptive learning within smart learning environments	Adaptive tasks matched to individual learning progress	Improved learning outcomes and engagement
P10 (Philippines)	Simulation-based, interactive learning	Virtual laboratories exploring hazard-free sustainable reactions	Improved conceptual understanding and scientific reasoning

P11 (Taiwan)	Film-based learning via the fishbowl discussion method	Analysis of environmental documentaries on pollution and climate	Increased engagement and classroom interaction
Interdisciplinary and systems-thinking frameworks			
P7 (South Africa)	Systems thinking; "curriculum as assemblage"	Climate change taught through chemical reactions and environmental data	Systems-level reasoning across scientific and social domains
P15 (UAE)	Climate-literacy framework integrating theory and practice	Real-world environmental problems linked to chemical principles	Environmental awareness and conceptual understanding
Equity and inclusive pedagogy			
P8 (South Africa / USA)	Inclusive, differentiated pedagogy	Sustainability tasks adapted for neurodivergent learners	Improved understanding across diverse student groups
P12 (Australia)	Individualised special-education instruction	Scaffolded tasks matched to student's learning levels	Gradual academic and social progress
P14 (Lebanon)	Transformative pedagogy emphasising teacher agency	Sustainability-focused teacher-training sessions	Long-term effects on attitudes and professional practice
Assessment reform, open resources, and curriculum redesign			
P3 (South Africa)	Curriculum redesign with data-driven evaluation	Assessment instruments modified to include sustainability tasks	Improved analytical, deeper-level understanding
P13 (South Africa)	Self-directed learning using open educational resources	Student-designed environmentally responsible laboratory procedures	Increased learner autonomy and responsibility

Appendix I

Table 3.2 Profiles of the fifteen Kazakhstan teachers and their reported barriers to green chemistry integration, grouped by school location (N = 15)

Resp.	Exp. (yrs)	Pedagogical challenge	Curriculum / resources	Institutional support & key factor
City schools (n = 10)				
R1	1–3	Limited time; overloaded curriculum	Lab only partly suitable	Informal support; cites training and prep time
R2	4–6	Abstract concepts hard to teach	Rigid exam curriculum; no equipment or materials	Limited support; cites resources and training
R3	1–3	Balancing theory with practice	Digital tools insufficient	No policy guidance; cites professional development
R4	1–3	Students can't link chemistry to sustainability	Slight curriculum support; eco-materials limited	Exam-focused admin; cites teacher motivation
R6	4–6	Time pressure; heavy curriculum	Insufficient lab equipment	Leadership-dependent; cites time and resources
R8	1–3	Integration needs extra preparation	Curriculum partly allows; basic resources	Informal support; cites teacher experience
R9	1–3	Students lack prior knowledge	Strongly exam-driven; equipment shortages	Institutional barriers; cites professional learning
R10	1–3	Very limited lesson time	Rigid curriculum; weak materials and digital tools	Minimal support; cites training and flexibility
R12	1–3	Sustainability seen as abstract	No curriculum direction; inadequate labs	Limited policy; cites continuous development
R13	1–3	Traditional methods unsuited	Minimal flexibility; lack of materials	Varies by school; cites teacher motivation
Village schools (n = 5)				
R5	1–3	No methodological guidance	Outdated lab conditions	Minimal encouragement; cites training and resources

R7	1–3	Adapting content to student's level	Low flexibility; no digital simulations	Cites teacher training as essential
R11	4–6	Explaining complex ideas clearly	Limited digital tools	Little admin guidance; cites quality resources
R14	1–3	Balancing syllabus with sustainability	Outdated lab equipment	Weak support; cites training as critical
R15	1–3	Lack of teaching strategies	Strict exam curriculum; no digital tools	No formal support; cites resource access

Note. R = respondent number. Experience is reported in the bands used at data collection (1-3 and 4-6 years); the whole sample was early career. The final column records the factor each respondent named as most influential for effective integration.

Appendix J

Interview question-RQ1

	Q1	**Q2**	**Q3**	**Q4**	**Q5**
Expert 1	5	4	5	4	4
Expert 2	4	4	5	4	5
Expert 3	5	5	5	5	4
Expert 4	4	4	3	3	4
Expert 5	5	5	4	5	5

Kendall's W Test Ranks

	Question 1	Question 2	Question 3	Question 4	Question 5
Mean Rank	3,50	3,00	3,00	2,50	3,00

Test Statistics

Kendall's coefficient of concordance W

	N	Raters	W	Chi-square	df	p
Value	5	5	0.471	9.42	4	.051

Примечание. H_a: W=0

Appendix K

Interview question-RQ2

	Q1	**Q2**	**Q3**	**Q4**	**Q5**
Expert 1	4	4	4	4	5
Expert 2	4	5	5	5	4
Expert 3	4	4	4	4	5
Expert 4	5	5	5	4	5
Expert 5	5	5	5	5	5

Kendall's W Test Ranks

	Question 1	Question 2	Question 3	Question 4	Question 5
Mean Rank	2,60	3,10	3,10	2,60	3,60

Test Statistics

Kendall's coefficient of concordance W

	N	Raters	W	Chi-square	df	p
Value	5	5	0.457	9.14	4	.005

Примечание. H_a: W=0

Appendix L

Pre- test/post-test - RQ3

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Expert 1	5	4	3	5	3	4	5	3	4	3
Expert 2	5	4	3	4	2	4	3	4	3	3
Expert 3	5	4	4	5	3	4	5	4	4	4
Expert 4	4	4	3	4	3	3	3	3	4	3
Expert 5	5	4	3	5	4	4	5	4	4	4

Kendall's W Test Ranks

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Mean Rank	9,10	6,20	3,00	8,60	2,50	5,20	6,80	4,50	5,40	3,70

Test Statistics

Kendall's coefficient of concordance W

	N	Raters	W	Chi-square	df	p
Value	5	10	0.436	17.4	9	.002

Примечание. H_a: W=0

Appendix M

Likert Scale Questions - RQ3

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Expert 1	4	4	4	4	4	4	4	4	4	4
Expert 2	5	4	4	4	4	4	4	4	4	5
Expert 3	4	3	3	4	4	4	4	4	4	4
Expert 4	4	4	4	4	4	3	4	3	3	4
Expert 5	5	4	4	4	5	4	5	4	4	4

Kendall's W Test Ranks

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Mean Rank	9,10	6,20	3,00	8,60	2,50	5,20	6,80	4,50	5,40	3,70

Test Statistics

Kendall's coefficient of concordance W

	N	Raters	W	Chi-square	df	p
Value	5	10	0.342	13.7	9	.008

Примечание. H_a: W=0

Appendix N

Results

Статистики шкалы надежности

	Кронбах α	*Items*	*N*
шкала	*0.87.*	*10*	*98*