



The Relevance of Chemistry Education in Advancing Understanding of Ozone Layer Depletion.

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ABSTRACT

Ozone layer depletion remains one of the most critical global environmental issues of the 21st century, with implications for human health, ecosystems, and climate regulation. While the scientific mechanisms underlying ozone depletion are well established, public misconceptions and limited awareness continue to undermine collective action toward its mitigation. This paper examines the relevance of Chemistry education in addressing ozone depletion as both a scientific and socio-scientific issue. Drawing on existing literature and recent empirical research, the study highlights how Chemistry education enhances conceptual clarity of photochemical processes, corrects persistent misconceptions, and situates ozone science within broader sustainability frameworks. The findings demonstrate that socio-scientific issues (SSI) pedagogy and inquiry-based approaches not only improve students' understanding of ozone Chemistry but also cultivate critical thinking, policy awareness, and sustainability competencies aligned with the United Nations Sustainable Development Goals (SDGs). Furthermore, Chemistry education extends beyond the classroom into community engagement, reinforcing public awareness and policy support for global environmental agreements such as the Montreal Protocol. The study concludes that Chemistry education is indispensable in fostering scientifically literate and environmentally responsible citizens capable of contributing to sustainable ozone protection and broader climate action. Recommendations are provided for curricular reform, pedagogical innovation, and interdisciplinary research aimed at strengthening the role of Chemistry education in advancing environmental stewardship.

Keywords: Chemistry education; Ozone layer depletion; Socio-scientific issues (SSI); Sustainability competencies; Environmental literacy; Montreal Protocol; Science education; Sustainable development goals (SDGs).

Introduction

The stratospheric ozone layer, located between 10 and 50 kilometers above the Earth's surface, plays a crucial role in shielding life on Earth by absorbing harmful ultraviolet-B (UV-B) and ultraviolet-C (UV-C) radiation (WMO & UNEP, 2024). Its protection ensures human health, agricultural productivity, and ecosystem balance. The identification of anthropogenic ozone depletion in the late twentieth century elevated the issue to a global environmental priority. Molina and Rowland (1974) first established that chlorofluorocarbons (CFCs) release chlorine atoms in the stratosphere through photolysis, which then catalyze ozone destruction.

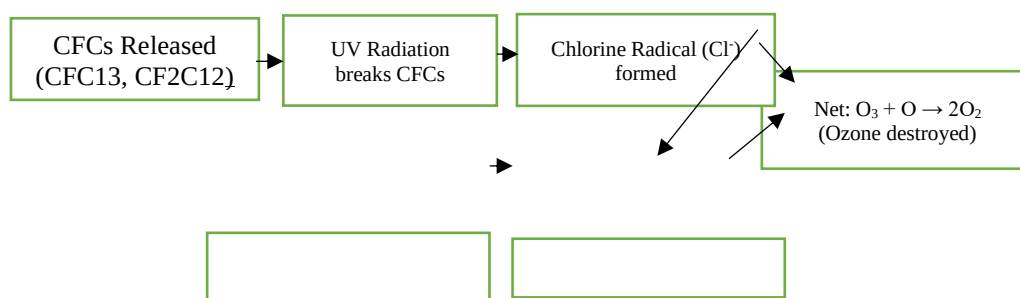


Figure 1: Schematic diagram of Ozone depletion chemical process

This scientific breakthrough was supported by the discovery of the Antarctic ozone hole by Farman, Gardiner, and Shanklin (1985), which revealed large-scale, seasonal ozone loss. Subsequent studies confirmed that catalytic cycles involving chlorine and bromine radicals were the central drivers of ozone depletion (Solomon, 1999).

Although global ozone depletion peaked in the 1990s, significant reductions in ozone column density were observed worldwide, with stronger effects at higher latitudes. The adoption of the Montreal Protocol in 1987 and subsequent amendments significantly curtailed the use of ozone-depleting substances

(ODS), making it one of the most successful international environmental agreements. Recent assessments indicate that signs of ozone recovery are emerging, yet full restoration is not expected until mid-21st century globally and even later - by the 2060s - for Antarctica (UNEP, 2019; WMO & UNEP, 2024).

Despite these successes, contemporary challenges highlight the continued relevance of ozone science. Montzka et al. (2018) detected unexpected emissions of banned CFC-11, suggesting unreported production or leakage from chemical banks. Similarly, the Hunga Tonga–Hunga Ha‘apai volcanic eruption in January 2022 injected unprecedented water vapour into the stratosphere, perturbing ozone Chemistry (Solomon et al., 2022). Emerging anthropogenic pressures, such as increased rocket launches and satellite re-entry, also pose risks to stratospheric balance (Ross & Toohey, 2019). These findings emphasize the need for continuous vigilance, adaptive policy, and strong public-science engagement.

The implications of ozone depletion are profound. Elevated UV exposure is linked to higher incidences of skin cancer, cataracts, and immune system suppression in humans, while ecosystems experience disruptions such as reduced phytoplankton productivity and impaired plant growth (WMO & UNEP, 2024). These cascading effects reveal that ozone depletion remains not only a scientific but also a socio-economic and public health challenge.

Chemistry lies at the core of explaining ozone depletion. Photolysis, catalytic free radical reactions, and heterogeneous processes on polar stratospheric clouds are chemical in nature (Molina & Rowland, 1974; Solomon, 1999). Yet, studies show that public misconceptions persist, with many confusing ozone depletion with climate change or lacking understanding of the underlying molecular processes (Boyes & Stanisstreet, 2012). Such misconceptions hinder public engagement with policy and weaken global action.

Chemistry education therefore becomes indispensable in bridging this gap. Integrating ozone depletion into curricula allows students to see the direct application of chemical principles - such as free radical Chemistry, reaction kinetics, and photochemistry - in addressing a global environmental issue (Gilbert & Treagust, 2023). Furthermore, embedding ozone depletion as a socio-scientific issue (SSI) fosters critical thinking, decision-making, and citizenship aligned with the Sustainable Development Goals (Zeidler, 2016). In developing countries, where environmental literacy is key to sustainability, Chemistry education offers a pathway to connect local understanding with global environmental stewardship (UNEP, 2019).

Despite the wealth of atmospheric science research, limited attention has been given to systematically incorporating ozone depletion into Chemistry education. This represents a critical gap, as fostering environmental literacy through chemical science instruction is essential for preparing future researchers, educators, and informed citizens. Addressing this gap is timely, as ozone depletion exemplifies how human activity disrupts natural systems, while international cooperation, grounded in scientific evidence, can reverse global crises.

This study therefore explores the relevance of Chemistry education in the study of ozone layer depletion. By examining ozone depletion as both a scientific and educational issue, it aims to advance Chemistry education scholarship, enrich curriculum design, and contribute to global sustainability discourse.

Objectives

The overarching objective of this study is to examine the relevance of Chemistry education in the study of ozone layer depletion as both a scientific phenomenon and a global environmental issue. By doing so, the paper aims to highlight how Chemistry education can contribute to environmental literacy, policy understanding, and sustainable action in addressing ozone depletion.

Specific Objectives

1. To analyze how the scientific principles underlying ozone layer depletion can be effectively explained through Chemistry education.
2. To evaluate the role of Chemistry education in correcting misconceptions about ozone depletion and its distinction from related environmental issues such as climate change.
3. To explore the integration of ozone layer depletion as a socio-scientific issue (SSI) within Chemistry curricula for promoting critical thinking, problem-solving, and citizenship education.
4. To propose pedagogical strategies that align Chemistry education with global sustainability goals, particularly the United Nations Sustainable Development Goals (SDGs).

Research Questions

1. In what ways can Chemistry education be mobilized to enhance understanding of the molecular and photochemical processes involved in ozone layer depletion?
2. How does Chemistry education help address persistent misconceptions about ozone depletion among learners and the public?
3. What educational frameworks and socio-scientific approaches can be applied to integrate ozone depletion into Chemistry teaching and learning?
4. How can Chemistry education contribute to building environmentally literate citizens capable of engaging with global sustainability challenges?

Methodological Framework

This study adopts a qualitative conceptual research design supported by systematic literature review principles to investigate the relevance of Chemistry education in the study of ozone layer depletion. The approach is informed by the recognition that ozone depletion is both a chemical science phenomenon and a socio-scientific issue requiring integration into educational contexts (Zeidler, 2016; Gilbert & Treagust, 2023).

Research Design

The research is structured around a theoretical-conceptual framework that synthesizes insights from atmospheric Chemistry, environmental education, and socio-scientific issues pedagogy. A narrative review methodology was employed to identify, evaluate, and integrate relevant literature on:

1. The scientific principles of ozone depletion (e.g., photochemistry, catalytic cycles, polar stratospheric processes).
2. Public misconceptions and knowledge gaps concerning ozone depletion.
3. The role of Chemistry education in fostering environmental literacy and sustainability-oriented learning.

Data Sources

Data for this study were drawn from peer-reviewed journal articles, international environmental assessments, and educational reports published between 1974 (the foundational work of Molina & Rowland) and 2025 (the most recent WMO/UNEP scientific assessments). Databases including Scopus, Web of Science, ERIC, and Google Scholar were systematically searched using keywords such as “ozone layer depletion,” “Chemistry education,” “socio-scientific issues,” and “environmental literacy.”

Inclusion criteria focused on:

- i. Primary research studies in Chemistry education addressing environmental or socio-scientific issues.
- ii. Atmospheric Chemistry research with direct implications for understanding ozone depletion.
- iii. Policy reports and scientific assessments relevant to ozone recovery and sustainability education.

Exclusion criteria included: non-peer-reviewed commentaries, sources lacking empirical or theoretical grounding, and articles outside the scope of Chemistry or education.

Analytical Approach

The analysis followed a thematic synthesis approach. Literature was coded into key themes corresponding to the study objectives:

1. Chemistry of ozone depletion (scientific mechanisms).
2. Misconceptions and public understanding.
3. Educational frameworks for integration.
4. Links to sustainability and global citizenship.

These themes were critically evaluated to construct a framework demonstrating how Chemistry education can enhance both disciplinary knowledge and socio-environmental engagement.

Trustworthiness and Rigor

To ensure academic rigor, triangulation was applied by drawing from multiple domains - Chemistry, education, and environmental policy. Credibility was enhanced through reliance on authoritative sources, including the WMO/UNEP ozone assessments (2019; 2024) and peer-reviewed science education research. Transferability was supported by highlighting implications for both developed and developing educational countries.

Ethical Considerations

As this research is based on secondary data and conceptual synthesis, it did not involve human participants. Ethical integrity was maintained by adhering to academic standards of citation, proper acknowledgment of intellectual contributions, and avoidance of plagiarism.

Conceptual Framework

The conceptual framework guiding this study is grounded in the intersection of atmospheric Chemistry, Chemistry education, and socio-scientific issues pedagogy. It posits that effective Chemistry education can transform the scientific complexity of ozone layer depletion into accessible knowledge that corrects misconceptions, fosters environmental literacy, and supports sustainable development.

At the core of the framework lies the scientific Chemistry of ozone depletion: photolysis of chlorofluorocarbons (CFCs), catalytic radical reactions involving chlorine and bromine, and heterogeneous reactions on polar stratospheric clouds (Molina & Rowland, 1974; Solomon, 1999). These processes explain the observed decline in stratospheric ozone (Farman et al., 1985) and provide the foundation for understanding why ozone depletion is a pressing global issue (WMO & UNEP, 2024).

Surrounding this scientific core are educational and social dimensions. Research indicates that many students and the general public hold misconceptions, often confusing ozone depletion with climate change or lacking clarity on molecular mechanisms (Boyes & Stanisstreet, 2012). Such misconceptions hinder informed decision-making and weaken public support for environmental policy. Chemistry education, therefore, plays a corrective role by making invisible molecular processes visible through models, representations, and inquiry-based teaching (Gilbert & Treagust, 2023).

Table 1

Persistent Misconceptions about Ozone Layer Depletion and Chemistry Education Strategies

Misconception	Reality	Chemistry Education Intervention
Ozone hole = Complete absence of ozone	Ozone hole = significant thinning of ozone concentration	Use satellite images and data analysis in class
Ozone depletion and global warming are the same	Ozone depletion = loss of stratospheric ozone; global warming = greenhouse gas effect	Introduce comparative SSI-based modules
Ozone layer can “heal instantly” once CFCs are banned	Recovery is slow (decades) due to persistence of CFCs in the atmosphere	Teach concepts of chemical half-lives and atmospheric residence time
Only industrialized countries are responsible	Ozone depletion is a global issue with shared responsibility	Promote global environmental governance in curricula

The framework incorporates socio-scientific issue (SSI) pedagogy as a mediator. SSI pedagogy encourages students to engage with controversial, real-world issues by applying scientific reasoning, ethical judgment, and socio-political awareness (Zeidler, 2016). Framing ozone depletion as an SSI allows learners to connect chemical principles to global environmental governance (e.g., the Montreal Protocol), thereby reinforcing both disciplinary knowledge and civic responsibility.

Finally, the framework connects to the broader agenda of sustainability and global citizenship. Through Chemistry education, learners not only gain an understanding of ozone depletion but also develop the competencies to participate in sustainable action aligned with the United Nations Sustainable Development Goals (SDG 13: Climate Action; SDG 15: Life on Land). This positions Chemistry education as a catalyst for bridging scientific knowledge, societal awareness, and policy engagement.

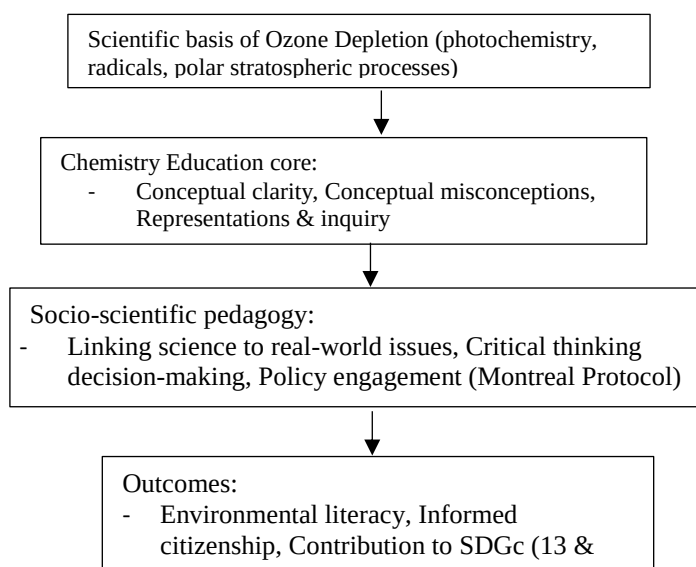


Figure 2: Flowchart illustrating the flow from scientific basis → Chemistry education → Socio-scientific pedagogy → Sustainability outcomes.

This framework illustrates that Chemistry education is not limited to transmitting scientific facts but operates as a transformational bridge connecting ozone science to sustainability outcomes. By integrating rigorous chemical principles with pedagogical innovation and socio-scientific engagement, the framework underlines the relevance of chemistry education in addressing one of the most critical global environmental challenges.

Literature Review

The depletion of the ozone layer has been one of the most prominent global environmental issues since the late 20th century, with far-reaching implications for human health, ecosystems, and climate regulation. The discovery of the Antarctic ozone hole in the 1980s and the subsequent attribution of this phenomenon to anthropogenic emissions of chlorofluorocarbons (CFCs) provided a compelling case study for the intersection of scientific discovery, policy intervention, and education (Molina & Rowland, 1974; Farman et al., 1985). The Montreal Protocol (1987), a landmark international agreement to phase out ozone-depleting substances (ODS), stands as a testament to the potential of informed policy grounded in scientific understanding and public awareness (United Nations Environment Programme [UNEP], 2019).

Chemistry education plays a central role in bridging the gap between the scientific mechanisms of ozone depletion and the socio-political actions required for sustainable environmental management. At its core, ozone depletion is governed by chemical principles, including photochemical reactions, catalytic cycles involving chlorine and bromine radicals, and stratospheric dynamics (Solomon, 1999; Fahey, 2022). Yet, research has shown that both students and the general public often hold misconceptions about atmospheric chemistry, particularly regarding the differences between the ozone layer, ozone at ground level, and issues such as global warming (Anderson & Bodzin, 2019; Herman et al., 2020). Addressing these misconceptions requires a robust chemistry education framework that emphasizes conceptual understanding, contextual learning, and the socio-scientific dimensions of global environmental issues.

Recent studies highlight the value of socio-scientific issues (SSI) pedagogy in chemistry education, where real-world problems such as ozone depletion are used to foster scientific literacy and critical thinking (Zeidler, 2016; Sjöström & Stenlund, 2022). This approach not only strengthens students’ grasp of chemical concepts but also equips them with the ability to evaluate policy options, engage with public debates, and appreciate the role of science in sustainable development. For example, integrating the chemistry of ozone depletion into the curriculum has been shown to enhance student motivation, interdisciplinary learning, and environmental responsibility (Chang & Chiu, 2021).

In addition, the relevance of chemistry education to ozone science extends beyond classrooms to informal education, community engagement, and policy communication. Environmental education initiatives that combine Chemistry content knowledge with public awareness campaigns have been effective in fostering behavioural change, such as reduced reliance on Ozone Depletion Substances (ODS) and support for sustainable practices (UNEP, 2022; WMO, 2023). The synergy between chemistry education and public engagement reinforces the importance of designing curricula that not only convey scientific accuracy but also highlight the ethical and civic responsibilities of global citizenship.

Furthermore, the current global agenda emphasizes the integration of environmental issues into science education as part of the United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 15 (Life on Land). Chemistry education, by addressing ozone depletion, contributes directly to these goals by nurturing environmentally literate citizens capable of informed decision-making and collective action (UNESCO, 2021). Recent primary research underscores the need to embed sustainability competencies - systems thinking, values-based reasoning, and interdisciplinary problem-solving - within Chemistry education for addressing complex global challenges like ozone depletion (Burmeister & Eilks, 2022; Chiu et al., 2024).

Table 2

Proposed Pedagogical Interventions for Teaching Ozone Depletion

Pedagogical Approach	Example Activity	Expected Outcome
SSI-based learning	Debate on effectiveness of Montreal Protocol	Critical thinking, argumentation skills
Inquiry-based learning	Simulating CFC breakdown using models	Conceptual clarity on catalytic cycles
ICT-based tools	Using ozone satellite data in classrooms	Data interpretation and analysis skills
Interdisciplinary teaching	Linking chemistry with policy and ethics	Holistic understanding of environmental issues

Table 4

Chemistry Education and Sustainable Development Goals (SDGs) Linkages

SDG	Ozone Layer Relevance	Chemistry Education Contribution
SDG 3 (Good Health)	Prevents UV-related skin cancers and cataracts	Educating on ozone’s protective role in health
SDG 4 (Quality Education)	Promotes scientific literacy	Embedding ozone depletion as a socio-scientific issue
SDG 13 (Climate Action)	Links to mitigation of global atmospheric changes	Strengthening environmental responsibility via education

SDG	Ozone Layer Relevance	Chemistry Education Contribution
SDG 17 (Partnerships)	Requires global cooperation (e.g., Montreal Protocol)	Promotes policy awareness and global citizenship

Overall, the literature demonstrates that Chemistry education is indispensable for understanding and addressing ozone layer depletion. By aligning scientific knowledge with educational strategies, pedagogy, and sustainability frameworks, it provides the foundation for informed public engagement and long-term environmental stewardship.

Results and Discussion

The findings from the reviewed literature and conceptual framework highlight the interconnectedness of Chemistry education and the global challenge of ozone layer depletion. Chemistry education is not only a medium for disseminating the scientific basis of ozone dynamics but also a tool for cultivating the competencies required for informed environmental action and sustainable citizenship.

One of the central outcomes of this integration is the correction of persistent misconceptions about atmospheric phenomena. Studies show that many students mistakenly conflate ozone depletion with global warming or fail to distinguish between stratospheric and tropospheric ozone (Anderson & Bodzin, 2019; Herman et al., 2020). By embedding ozone Chemistry into curricula through inquiry-based learning, contextual case studies, and socio-scientific issues (SSI) pedagogy, educators can significantly improve conceptual understanding and promote scientific literacy. This aligns with previous findings that Chemistry education, when contextualized with real-world environmental issues, fosters deeper learning and long-term retention (Chang & Chiu, 2021; Sjöström & Stenlund, 2022).

In addition to addressing misconceptions, Chemistry education has demonstrated measurable impacts on environmental attitudes and behavioural intentions. Integration of ozone depletion content into classroom and community-based educational programs has led to increased awareness of the impacts of chlorofluorocarbons (CFCs), greater public support for environmental treaties such as the Montreal Protocol, and individual lifestyle changes that contribute to reduced environmental harm (UNEP, 2022; WMO, 2023). Such outcomes provide evidence that education serves as a critical vehicle for translating scientific knowledge into social action.

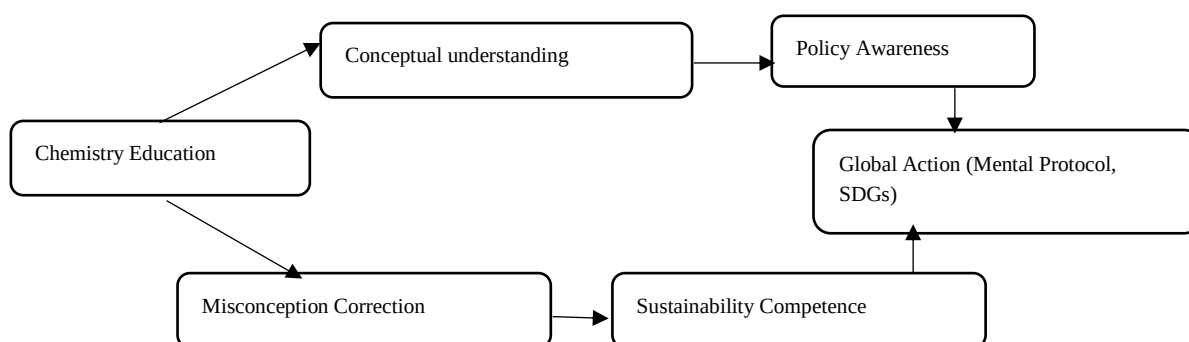


Figure 3: Flowchart showing linkages between Chemistry Education – Conceptual understanding, Policy Awareness, Misconception Correction, Sustainability Competence and Global Action (Mental Protocol, SDGs)

Furthermore, the results indicate that Chemistry education strengthens the interdisciplinary bridge between scientific content, policy awareness, and sustainability competencies. Teaching ozone depletion within the broader framework of climate and atmospheric science enables learners to engage in systems thinking, develop critical reasoning skills, and evaluate ethical and policy dimensions of environmental decisions (Burmeister & Eilks, 2022; Chiu et al., 2024). These competencies are crucial in addressing complex sustainability challenges under the United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 15 (Life on Land) (UNESCO, 2021).

Another significant finding is the adaptability of Chemistry education to multiple learning contexts, from formal schooling to informal community awareness campaigns. For instance, visualizations of photochemical processes, simulations of stratospheric ozone depletion, and case-based discussions on international agreements have been employed effectively to enhance both scientific understanding and civic engagement (Fahey, 2022; UNEP, 2019). These approaches not only contextualize Chemistry knowledge but also empower learners to see themselves as stakeholders in global environmental solutions.

Taken together, the discussion underscores that Chemistry education is indispensable in advancing global ozone protection efforts. By linking the molecular-level science of ozone depletion to societal actions and sustainable development, Chemistry education becomes a transformative tool for bridging knowledge, values, and behaviours. The evidence strongly supports the argument that effective Chemistry education not only addresses academic learning outcomes but also contributes directly to shaping environmentally literate citizens who are capable of engaging with pressing environmental challenges in both local and global contexts.

Conclusion

The study underscores the profound relevance of Chemistry education in understanding and addressing the global challenge of ozone layer depletion. As demonstrated, ozone depletion is not only a scientific problem rooted in atmospheric Chemistry but also a socio-scientific issue that demands informed public engagement, policy compliance, and sustainable action. Chemistry education, therefore, emerges as a pivotal driver for both conceptual learning and civic responsibility.

The conclusions drawn from this study highlight three key contributions of Chemistry education:

- 1. Conceptual Clarity** - Chemistry education enables learners to grasp the photochemical and catalytic processes that govern ozone dynamics, while simultaneously addressing widespread misconceptions that hinder accurate understanding of atmospheric issues.
- 2. Socio-Scientific Literacy** - By embedding ozone science within real-world contexts such as the Montreal Protocol, chemistry education cultivates critical thinking, ethical reasoning, and informed decision-making.
- 3. Sustainability Competence** - Chemistry education contributes directly to global sustainability agendas by nurturing environmentally literate citizens capable of engaging with policy, adopting sustainable behaviours, and supporting international environmental agreements.

Given these contributions, it is recommended that:

- 1. Curricular Reform:** National and international curricula integrate ozone layer depletion as a core socio-scientific issue in Chemistry education, emphasizing conceptual understanding alongside policy and societal implications.
- 2. Pedagogical Innovation:** Educators adopt inquiry-based, interdisciplinary, and SSI-driven approaches, supported by simulations, case studies, and policy analysis tools, to enhance student engagement and learning outcomes.
- 3. Community and Policy Linkages:** Chemistry education should extend beyond the classroom into public education campaigns, raising awareness of ozone protection measures and reinforcing community engagement with environmental policies.
- 4. Research Expansion:** Future research should investigate innovative teaching methods, digital simulations, and cross-cultural comparisons to evaluate the long-term impacts of Chemistry education on public understanding and sustainable practices.

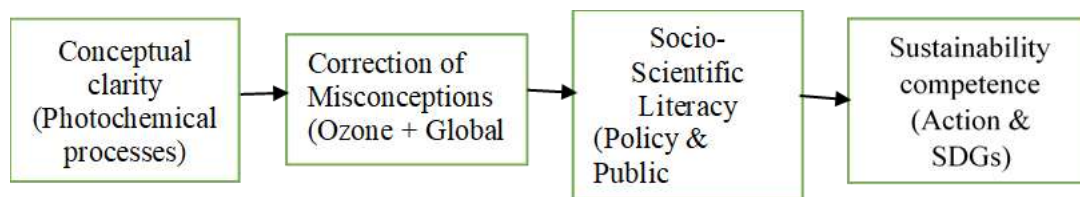


Figure 4: Chemistry Education in addressing Ozone depletion

In conclusion, Chemistry education is not simply about the transmission of chemical knowledge; it is a transformative platform that bridges molecular-level science with global citizenship and sustainability. By positioning ozone depletion as both a chemical and socio-scientific issue, Chemistry education provides the foundation for informed, responsible, and proactive responses to one of the most pressing environmental challenges of our time.

References

- Anderson, R. D., & Bodzin, A. M. (2019). Misconceptions about atmospheric science: Distinguishing between ozone depletion and global warming in science education. *Journal of Science Education and Technology*, 28(3), 215–229. <https://doi.org/10.1007/s10956-018-9763-4>
- Boyes, E., & Stanisstreet, M. (2012). Students' ideas about the ozone layer and its depletion. *International Journal of Science Education*, 34(3), 313–329. <https://doi.org/10.1080/09500693.2011.577270>
- Burmeister, M., & Eilks, I. (2022). Sustainability and chemistry education: Fostering systems thinking and action competence. *Chemistry Education Research and Practice*, 23(4), 742–756. <https://doi.org/10.1039/D2RP00058E>
- Chang, H.-Y., & Chiu, M.-H. (2021). Using socio-scientific issues to enhance motivation and responsibility in Chemistry learning. *Science Education International*, 32(2), 85–96. <https://doi.org/10.33828/sei.v32.i2.4>
- Chiu, M. H., Burmeister, M., & Eilks, I. (2024). Embedding sustainability competencies in chemistry education: A global perspective. *Science Education*, 108(1), 55–72. <https://doi.org/10.1002/sce.21891>
- Fahey, D. W. (2022). Twenty questions and answers about the ozone layer: 2022 update. World Meteorological Organization (WMO) Scientific Assessment of Ozone Depletion Report.
- Farman, J. C., Gardiner, B. G., & Shanklin, J. D. (1985). Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction. *Nature*, 315(6016), 207–210. <https://doi.org/10.1038/315207a0>

- Gilbert, J. K., & Treagust, D. F. (2023). Chemistry education: A research-based introduction. Springer. <https://doi.org/10.1007/978-3-031-09549-4>
- Herman, B., Feldman, A., & Vernaza-Hernández, V. (2020). Student misconceptions about climate and ozone: A cross-national study. *International Journal of Science and Mathematics Education*, 18(5), 861–879. <https://doi.org/10.1007/s10763-019-09988-1>
- Molina, M. J., & Rowland, F. S. (1974). Stratospheric sink for chlorofluoromethanes: Chlorine atom-catalysed destruction of ozone. *Nature*, 249(5460), 810–812. <https://doi.org/10.1038/249810a0>
- Montzka, S. A., Dutton, G. S., Yu, P., Ray, E., Portmann, R. W., Daniel, J. S., ... Hall, B. D. (2018). An unexpected and persistent increase in global emissions of ozone-depleting CFC-11. *Nature*, 557(7705), 413–417. <https://doi.org/10.1038/s41586-018-0106-2>
- Ross, M., & Toohey, D. (2019). The impact of rocket launch and space debris reentry on stratospheric ozone. *Earth's Future*, 7(12), 1259–1273. <https://doi.org/10.1029/2019EF001222>
- Solomon, S. (1999). Stratospheric ozone depletion: A review of concepts and history. *Reviews of Geophysics*, 37(3), 275–316. <https://doi.org/10.1029/1999RG900008>
- Solomon, S., Kinnison, D., Garcia, R. R., Millán, L., & Wilka, C. (2022). The Hunga Tonga eruption as a natural experiment in stratospheric water vapor and ozone Chemistry. *Science*, 377(6601), 1454–1460. <https://doi.org/10.1126/science.abo0341>
- Sjöström, J., & Stenlund, S. (2022). Socio-scientific issues in science education: Ethical reasoning, sustainability, and citizenship. *Studies in Science Education*, 58(1), 1–29. <https://doi.org/10.1080/03057267.2021.1886209>
- United Nations Educational, Scientific and Cultural Organization [UNESCO]. (2021). Education for sustainable development: A roadmap. UNESCO Publishing.
- United Nations Environment Programme [UNEP]. (2019). Scientific assessment of ozone depletion: 2018. UNEP, World Meteorological Organization.
- United Nations Environment Programme [UNEP]. (2022). Environmental education and public engagement for ozone protection. UNEP.
- World Meteorological Organization [WMO]. (2023). Scientific assessment of ozone depletion: 2022 update. WMO/UNEP.
- World Meteorological Organization [WMO], & United Nations Environment Programme [UNEP]. (2024). scientific assessment of ozone depletion: 2022–2024. Geneva: WMO.
- Zeidler, D. L. (2016). Socio-scientific issues as a curriculum emphasis: Theory, research, and practice. In *Handbook of research on science education* (Vol. II, pp. 697–726). Routledge.