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Climate Change in Teaching Chemistry: Focusing on the Use of Charts

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Abstract

This paper aims to present research focused on fostering digital skills and data literacy in grammar schools through the teaching of the topic "Climate Change" during chemistry lessons. In the first phase, a set of four methodologies was developed – Earth's Climate System, Monitoring air quality, Acid rains and their impact on the environment, Greenhouse effect and global warming. Each methodology included a teacher's guide and a student worksheet. The methodologies focused on developing data literacy; to process the data, students worked with charts and data from well-known climate atlases, such as Copernicus Interactive Climate Atlas Climate (https://atlas.climate.copernicus.eu/), Atlas of Canada (https://climateatlas.ca/) as well as with the data from the Slovak Hydrometeorological Institute (SHMI, https://www.shmu.sk), which provides up-to-date meteorological, hydrological, and climatological information in Slovakia. These methodologies were designed to help students develop their ability to seek and analyse data on air quality at both national and regional levels, identify greenhouse gases with a high global warming potential, understand their role in atmospheric processes, explore causality, and propose potential solutions to global problems based on the knowledge acquired. A pilot testing of these methodologies involved 50 3rd-year grammar school students. To assess the effectiveness of teaching using these methodologies, students completed exit cards. The evaluation of students' responses indicated that they gained knowledge about the causes of air pollution, substances that pollute the environment (including their threshold concentration values), appreciated working with climate atlases and SHMI, and learned how to seek and analyse data based on various criteria. Students showed interest in learning about combating climate change and improving air quality.

Keywords: chemistry, data literacy, climate atlas, methodology, development

1. Introduction

Climate change is the most pressing environmental issue today (IPCC, 2023). The negative impacts of climate change vary in frequency and intensity across different regions. These impacts include rising average temperatures, heatwaves, floods, severe droughts and wildfires, melting icebergs, rising sea and ocean levels, loss of biodiversity, species extinction, increased

prevalence of pathogens and diseases, degradation of forest ecosystems, declining water sources, soil erosion, and extreme weather events such as storms, hurricanes, and gales. It negatively affects food and water security, human health, the economy, and entire societies, leading to environmental degradation and economic losses (IPCC, 2023). The goal of the EU climate policy is to achieve climate neutrality in Europe by 2050 (European Commission, 2019). Effectively mitigating climate change requires the development of new knowledge, skills, and ways of thinking and acting. The education system must respond by adapting curricula and teaching methods (Gudmanian et al., 2020; UNESCO, 2014).

Teaching about climate change encompasses all branches of the natural sciences. It should be delivered in line with the recommendations of A Framework for K–12 Science Education, integrating climate and climate change science across the K–12 curriculum, both within and beyond STEM (science, technology, engineering, and mathematics) subjects (NSTA, 2024).

Teachers must consider several key aspects when teaching about climate change (Teaching the Future, 2021): Climate data are often vast and complex, spanning various spatial scales and including access to authentic, original datasets. Visual representations of these data, such as charts, tables, and maps, enhance comprehension. As a result, students can quickly comprehend climate change and its progression. Visual resources make teaching more interactive and help students understand and retain information more effectively when they can see the data. The visualisation of climate data fosters critical thinking. Students learn to interpret data, identify trends, and draw informed conclusions. Climate model data enhance students' engagement in discussions, reasoning, and proposing solutions to mitigate these challenges in the future. Integrating climate data visualisation into teaching prepares students for real-world challenges and enhances their ability to develop meaningful solutions to climate change.

1.1 Climate Change in Teaching Chemistry

In recent years, chemistry has been perceived negatively by the public. Environmental pollution is likely a contributing factor to students' reluctance to study chemistry. Without proper context, chemistry knowledge is not perceived as useful for addressing everyday challenges. Schnotz (2015) explains that, from a constructivist perspective, the knowledge acquired through systematic schooling remains disconnected from everyday knowledge, and as a result, school knowledge is not applied in practice. This is due to the fact that chemistry teaching often relies on traditional theoretical divisions – such as inorganic, analytical, physical, and organic chemistry – and follows a fragmented approach, covering numerous disconnected topics. Contextual explanations are insufficient because this approach to teaching provides limited opportunities for situated learning (Baumert & Lehmann, 1997). However, chemistry should be taught by contextualising its relevance to society. Teaching the chemistry of climate change allows students to perceive chemistry as an integrated science rather than a collection of fragmented disciplines. According to Sivaram and Sen Gupta (2024), chemistry must be taught in a way that conveys its contextual relevance to society.

Chemistry, with its significant overlap with physics, biology, and geography, is expected to play a central role in addressing climate change challenges, particularly in areas such as environmental protection, population dynamics, waste management, public health, water resources, and energy.

Climate change is a current topic that should be included in chemistry teaching, as chemistry plays a key role in understanding the processes driving climate change and in developing solutions. Various aspects of climate change, such as greenhouse gases, air pollution, and ocean acidification, are directly linked to chemical processes. Table 1 presents examples of climate change integration into chemistry teaching at the grammar school level. It presents selected

climate change topics along with educational goals that should be established for teaching, based on the work of selected authors and researchers (e.g., Enright et al., 2024; Lamanauskas & Makarskaitė-Petkevičienė, 2023). It also illustrates how these topics align with the educational standards for chemistry in the Slovak State Educational Programme (Sivákova et al., 2009; National Institute for Education/ŠPÚ, 2014).

Table 1. The integration of climate change into grammar school chemistry teaching

Climate change education topics based on Enright et al., 2024; Lamanauskas & Makarskaitė-Petkevičienė, 2023		**Educational standards for chemistry at the grammar school level (Slovakia)**		
What to teach	**How to teach it**	**When to teach it**	**What to teach**	**How to teach it**
		Thematic unit	**Content standard**	**Performance standard**
Air pollution	The connection between chemical processes in fuel combustion and the formation of sulphur dioxide, nitrogen oxides, and other harmful pollutants that contaminate the air and contribute to environmental pollution. Chemical reactions responsible for acid rain formation and its impact on ecosystems	Elements and their inorganic compounds	Combustion (complete, incomplete)	Comparison of the attributes of CO and CO_2. Specification of the attributes of SO_2. Classification of oxides based on their reaction with water (SO_2, SO_3, CO_2). Explanation of the causes of acid rain.
Greenhouse effect and greenhouse gases	Explanation of how greenhouse gases (CO_2, methane, nitrous oxide) contribute to Earth's warming. Listing of chemical reactions responsible for greenhouse gas formation (e.g., fossil fuel combustion). Analysis of the impact of rising CO_2 concentrations on the atmosphere and temperature.	Elements and their inorganic compounds	Greenhouse effect Global warming	Comparison of the attributes of CO and CO_2.
Protection of the ozone layer	Linking chemical reactions responsible for ozone layer destruction (e.g., chlorofluorocarbons). Explanation of how these reactions affect our protection from harmful UV radiation and contribute to climate change.	Hydrocarbons important in practice	Fossil resource	Comparison of fossil fuels in terms of the ecological consequences of their extraction, processing, and use, as well as the content of harmful additives.
		Hydrocarbon derivatives	Freons	Explanation of the use of Freons, their chemical effects on the ozone layer, and the resulting environmental impact.

Source: Own design

2. Materials and Methods

Witte (2024) defines data literacy as “the ability to explore, understand, and communicate with data in context.” Specialised literature mentions various skills for developing comprehensive data literacy in schools. Lee et al. (2022) and Burr et al. (2021) have identified eleven skills necessary for data literacy: Define questions, Plan study design, Data collection (new data

e research, a set of four methodologies was developed: Earth's Climate System, Monitoring), Data retrieval (existing data), Data organisation, Data analysis, Data visualization, Data interpretation, Communicating results, Data evaluation, New ideas/questions.

The aim of the research was to develop data literacy among grammar school students through the teaching of the topic “Climate Change” in chemistry lessons.

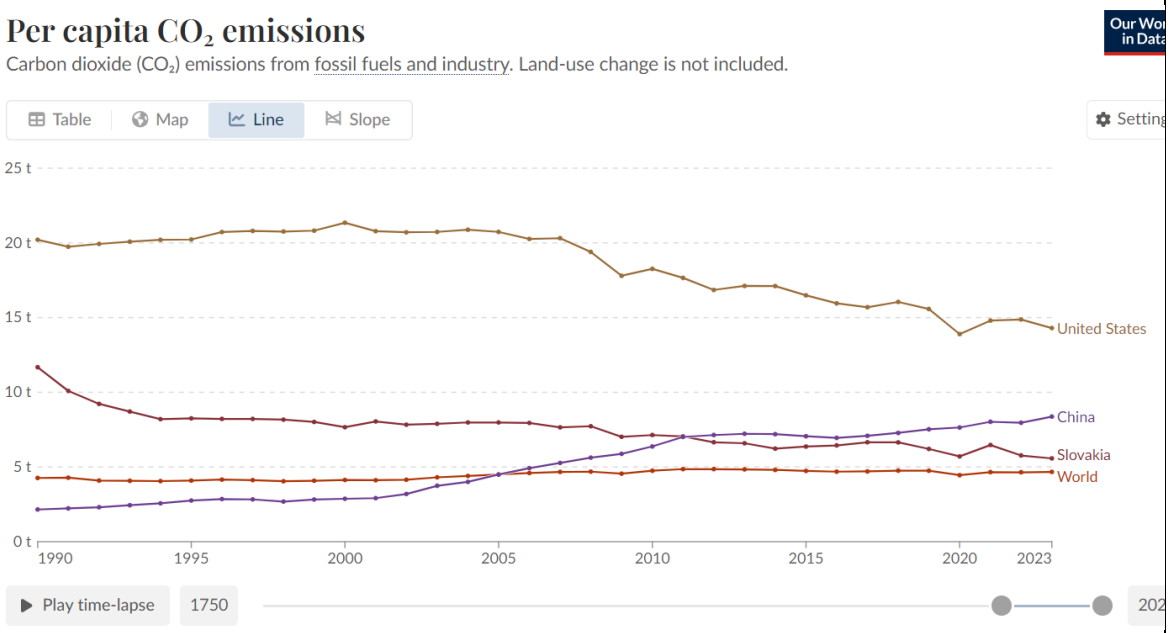
In the preparation phase of th Air Quality, Acid Rain and Its Impact on the Environment, and the Greenhouse Effect and Global Warming. All methodologies were designed in collaboration with chemistry didactics experts at the Faculty of Science, Pavol Jozef Šafárik University in Košice, and grammar school teachers. Each methodology included a teacher’s guide and a student worksheet.

The objectives of the methodologies were to develop students' data literacy; to process the data, students worked with maps, graphs, tables, and data from well-known climate atlases, such as the Copernicus Interactive Climate Atlas (https://atlas.climate.copernicus.eu/), the Atlas of Canada (https://climateatlas.ca/), and data from the Slovak Hydrometeorological Institute (SHMI, https://www.shmu.sk), which provides up-to-date meteorological, hydrological, and climatological information for Slovakia. The tasks in worksheets were designed to help students develop their ability to seek and analyse data on air quality at both national and regional levels, identify greenhouse gases with a high global warming potential, understand their role in atmospheric processes, explore causality, and propose potential solutions to global problems based on the knowledge acquired. Specific interactive educational activities were also used, such as "Air Quality" and "Impacts of Climate Change," available on the UCAR Center for Science Education (2024), which supported active learning, collaboration, and discussion among students.

Table 2 presents an example of a student worksheet for the topic Monitoring Air Quality. The students worked in pairs. Their activities were guided by the tasks in the worksheet. During the activity, the teacher motivated and guided students by asking relevant questions.

Table 2. An example of tasks in the student worksheet for the topic Monitoring Air Quality

Task 1. On the Our World in Data website, (https://ourworldindata.org/co2-and-greenhouse-gas-emissions) create a chart to present data on CO_2 emissions per capita in the following countries: Slovakia, China, United States, and the whole world between 1990 and 2023.



A demonstration of a chart created by students

Task 2. Analyse the data in the chart and answer the following questions.

Circle your answers.

1. **Which country had the highest CO_2 emissions per capita in 2023?**
   a) Slovakia
   b) China
   c) United States of America
   d) World average
2. **How have per capita CO_2 emissions in the United States changed from 1990 to 2023?**
   a) They increased consistently.
   b) They decreased with minor fluctuations.
   c) They remained approximately the same.
   d) First, they soared, followed by a sharp decline.
3. **Choose the correct statement about the trend in per capita CO_2 emissions in China and Slovakia.**
   a) Emissions in China steadily decreased, while in Slovakia they increased.
   b) Emissions in China increased, while in Slovakia they decreased slightly.
   c) In both countries, emissions decreased.
   d) Emissions in China and Slovakia increased at the same rate.

Task 3. Calculate the required values based on the data from the chart for Slovakia. Use the auto-scaling function for calculations.

a) The difference in CO_2 emissions per capita between 1990 and 2023.
b) The average annual change in CO_2 emissions between 1990 and 2023.
c) If this trend were to continue, what would the approximate CO2 emissions per capita be in 2030?

Task 4. In pairs, discuss the possibilities for decreasing CO_2 emissions in Slovakia.

a) Propose at least three measures Slovakia could take to continue decreasing CO_2 emissions.
b) How can we, as individuals, help decrease CO_2 emissions?
c) Do you think Slovakia has a chance of achieving carbon neutrality by 2050 (as part of the European Green Deal)? Explain why or why not.

Source: Own design

A pilot verification of the prepared methodologies involved 50 3rd-year grammar school students. The teacher participating in the research attended a two-hour training seminar in October 2023, where she learned how to use our methodologies in teaching. She taught using them during the two-month period from November to December 2024. The set consisted of four methodologies, which she used every other week.

3. Results

3.1 Evaluation of Teaching Using Methodologies on the Topic of Climate Change

At the end of the class taught using the prepared methodologies, students completed a 3-2-1 exit ticket, which encouraged them to reflect on and summarise their learning while identifying areas that needed more attention. Students were asked to answer three questions: 3 new facts they learned, 2 pieces of the most interesting information, and 1 question they still had. Student responses (see Table 3) were analysed in relation to developing specialised knowledge, enhancing data literacy skills, and forming attitudes and opinions about climate change.

Table 3. Results from the 3-2-1 exit ticket in the Monitoring Air Quality in Slovakia worksheet

Area of development	**Selected student responses**
Acquired knowledge	**Today I learned...** What the greenhouse effect is. What the greenhouse gases are. What climate change is. What PM_{10} is. Which specific substances pollute the environment. The causes and consequences of climate change. How poor air quality affects the human body. The location of monitoring stations in Slovakia. How the concentrations of air pollutants are measured at these stations.
Acquired data literacy skills Data retrieval (existing data), Data organisation, Data analysis, Data interpretation Data evaluation Communicating results	**What I found the most interesting:** I learned how to seek and analyse data based on various criteria on the Slovak Hydrometeorological Institute (SHMI). Working with the database on the SHMI website. What happens when threshold concentration values of substances in the air are exceeded (warning signs). How to identify and explain the fluctuation of air quality throughout the year in different places around Košice. How to calculate whether a limit has been exceeded. How to calculate how much these limits have been exceeded. Group work and discussion. Poster creation.
Attitudes and opinions about climate change	**I would still like to ask..** Why people fail to realise what is happening? When will the situation get better? Can we have a future without climate change? How can I help to improve the situation? How can we reduce global warming without making big changes to transportation? How much can one person influence the concentrations of air pollutants?

Source: Own design

In addition to gaining conceptual knowledge on the topic, the teaching also had an impact on shaping students' attitudes and opinions, particularly in terms of analyzing the effects of climate change on the environment and considering possible solutions to these issues. This is evidenced by numerous student reflections at the end of the lessons, such as: Is there a chance

to improve air quality? How can we further reduce emissions? What can I do to help improve this situation? How can we reduce global warming without making major changes to transport?, and similar questions.

4. Conclusion

The teaching of the topic Climate Change presented in this paper was based on current scientific knowledge and data, which can be easily used by teachers and schools The evaluation of teaching using the methodologies designed for the topic Climate Change showed that this approach was engaging for students because they worked with real-world, authentic open data and gained new knowledge (e.g., about climate change, air pollutants, and greenhouse gases). Students appreciated working with climate atlases and digital databases, which helped enhance their data literacy skills. Teaching with these methodologies facilitated a deeper understanding of the seriousness of climate change among students. They reflected more on the issue of air quality, which shaped their attitudes and opinions. Students also showed interest in learning about combating climate change and improving air quality. This approach creates the conditions for their active involvement in solving environmental problems at the local, regional, and national levels.

To support the comprehensive development of data literacy, it is necessary to include not only tasks and activities focused on analysing and interpreting existing data, but also those that involve planning and data collection in the teaching about climate change. Such activities should be implemented through project-based learning and interdisciplinary teaching, both in school and in out-of-school settings.

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