Part 10 / Strand 10

Environment, Health And Science Education

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Part 10 / Strand 10 Environment, Health And Science Education

Theories, methods, and practices about environmental, ecological, earth, health, and medicine education. Includes debate about literacies and approaches related to the environment, including indigenous perspectives and connection with more comprehensive aspects of justice as well as planetary well-being, and the design, development, and evaluation of the impact of programmes and experiences.

Sub-themes:

1) Environmental Literacy and Science Education
2) Health and Medicine Education
3) Indigenous Perspectives on Environmental Education
4) Justice and Equity in Environmental Science Education

Contents

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Strand 10: Environment, Health, And Science Education – Exploring Teachers' And Learners' Conceptions, Competence, And Agency In Times Of Environmental And Health Challenges

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Strand 10 of the ESERA conference focuses on the intersections of environment, health, and science education, bringing together research that examines how learners and teachers engage with scientific ideas closely connected to individual well-being, societal challenges, and environmental sustainability. Research in this strand addresses pressing issues such as climate change, environmental degradation, and health-related socioscientific issues, while also exploring the pedagogical, conceptual, and affective dimensions of teaching and learning science in these contexts. The papers in this chapter reflect the breadth of work within Strand 10, with a strong emphasis on learners' and teachers' conceptions of environmental and health-related phenomena. Contributions were organized into five subsections, namely, "Climate Change Education and the Climate Crisis", "Transformative Learning in Environmental Education", "Getting Engaged with Nature and Environment", "Sex Education, Equality, and Menstruation", and "Health Conceptions in Social Media".

Most contributions investigate learners' and teachers' understandings and competencies related to environmental topics, including the greenhouse effect, groundwater systems, climate change, and the ozone layer, examining both scientifically accurate conceptions and persistent misconceptions among students and preservice teachers. Together, these studies highlight the complexity of climate science learning and the need for instructional approaches that explicitly attend to systems thinking, uncertainty, and human influences on environmental processes as well as addressing obstacles to integrative, action-competence-oriented climate education. Related papers extend this focus on conceptual understanding to other environmental and health topics, including menstruation and metabolic disease. These contributions illustrate how scientific knowledge in environmental and health domains is intertwined with everyday experiences, cultural norms, and personal relevance. By analysing learners' and teachers' existing ideas, these studies provide insights into challenges for teaching conceptually demanding and socially sensitive topics in science classrooms.

Beyond conceptual knowledge, several papers address environmental competencies, action-oriented education, behaviours, and dispositions. Research on children's connection to nature and preservice teachers' environmental behaviours foregrounds affective and ethical dimensions of science education, emphasizing the importance of fostering responsibility, care, and engagement alongside scientific understanding. Studies examining climate change competence similarly adopt a broader perspective on learning, focusing on the integration of knowledge, skills, and attitudes necessary for thoughtful participation in societal decision-making. Studies on health conceptions argue for inclusive education that addresses stigma and fosters gender equity. A related contribution examines how health knowledge is conceptualized and communicated through digital and social media sources.

Pedagogical design is another key theme across the chapter. Contributions examining the use of learning cycles in high school environmental education and students' development of prototype environmental sensors highlight inquiry-based and design-oriented approaches that actively engage learners in scientific practices. These studies also point to the potential of digital tools and hands-on technologies for supporting data-informed reasoning and deeper engagement with environmental issues.

A notable trend across the chapter is the central role of teacher education. Multiple papers focus on preservice teachers' conceptions, competencies, instructional practices, and behaviours related to environment and health, underscoring the importance of teacher preparation for addressing socioscientific issues in meaningful ways. A second trend is the field's movement toward competency-based and action-oriented frameworks that integrate knowledge, skills, values, and agency. Third, questions of equity — relating to gender, culture, and social justice — recur across subsections, reflecting a broader understanding of what science education in these domains is for. In this regard, these studies highlight both opportunities and tensions in supporting future teachers as they navigate curricular expectations, scientific complexity, and societal relevance.

Positioned within the wider field of science education research, the work in this strand contributes to ongoing debates about the purposes of science education in the context of global environmental change and public health challenges. The papers advance conceptions of scientific literacy that extend beyond content mastery to include critical thinking, ethical awareness, and agency. In doing so, they align closely with the conference themes of sustainability and digital advances, illustrating how environment and health education can support learners in engaging with complex challenges that will shape present and future societies.

Section: Climate Change Education And The Climate Crisis

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Alternative Conceptions About The Greenhouse Effect: An Analysis Across Educational Stages

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This study analyses alternative conceptions of the greenhouse effect among high school and postgraduate participants. To this end, responses to an open-ended questionnaire were qualitatively evaluated, using as the analytic instrument one dimension of a construct map developed within a broader study to explore students' initial ideas about the regulation of the planet's climate. The sample comprised 131 participants, divided into two groups: Middle school, high school students, and postgraduate students and active teachers. The findings show that, although educational level influences the level of technical detail in the responses, alternative conceptions persist across all levels. The most frequent include identifying the greenhouse effect as part of the ozone layer, equating it with climate change, and failing to acknowledge its regulatory role in the Earth's climate system. While this latter difficulty is more evident at initial stages, it also appears at advanced levels, underscoring the need to implement targeted teaching, learning strategies that explicitly address these alternative conceptions across all educational stages.

Keywords: Greenhouse effect, alternative conceptions, persistent ideas.

Introduction

Science education plays a pivotal role in shaping an informed citizenry capable of making evidence-based decisions regarding contemporary environmental challenges such as climate change. A sound understanding of the factors that regulate the climate is essential for students, from primary education through university, to develop a critical perspective on human influence on the environment (Morote et al., 2021). Indeed, UNESCO (2021) emphasizes the importance of integrating climate knowledge into school curricula, noting that a deep understanding of these issues is crucial for future citizens.

Nonetheless, numerous learning difficulties persist regarding the regulation of the Earth's climate and its regulatory factors. In particular, a recurrent difficulty is the alternative conception that the ozone layer is a climatic regulator or forms part of the greenhouse effect. This idea often arises from its confused treatment in textbooks (Sakarya et al., 2023), where explanations of these two atmospheric phenomena are insufficiently differentiated, the terminology is complex, and both elements are intrinsically challenging to grasp (Andersson & Wallin, 2000).

This study therefore aims to analyse participants' conceptions of the greenhouse effect across different educational stages, and thus their persistence, with a view to informing future instructional designs that help students overcome these learning difficulties.

Background

In the field of science education, didactic transposition adapts complex phenomena to make them more accessible to students, aligning with their cognitive capacities and supporting progression (Adúriz-Bravo, 2009). In this study, we define the school-science idea of the greenhouse effect

as the atmospheric process of absorption and re-emission of infrared radiation, explicitly highlighting its positive nature as a regulatory factor of the climate, essential for life.

A range of studies has examined the ideas that students and teachers hold about atmospheric phenomena and components. Papadimitriou (2004) investigated prospective primary teachers' conceptions of climate change, the greenhouse effect, and the ozone layer using open-ended questionnaires. The study concluded that most of these preservice teachers struggled to differentiate among these concepts. For example, they believed that the ozone hole is directly related to global warming or that gases in the ozone layer contribute to the greenhouse effect. Along similar lines, though focused exclusively on the greenhouse effect, Sakarya et al. (2023), using open-ended questionnaires, found that students in a Master's program in Environmental Education maintained alternative conceptions about this phenomenon, showing difficulties in understanding the role of atmospheric gases involved and the physical mechanisms underlying the retention of terrestrial heat.

These findings underscore the need to explore new instructional approaches that can help overcome such learning difficulties. In this regard, model-based teaching is conceived as a comprehensive didactic approach in which the teacher structures learning around activities that foster deep understanding and critical thinking, thereby enabling more accurate and reflective explanations of the phenomenon (Oliva, 2019).

This strategy rests on the idea that school models function as representations mediating between learners and scientific knowledge, whose relationship to phenomena is one of similarity rather than exact reproduction of reality (Adúriz-Bravo, 2009). From a semantic view of theories, a theoretical model may take multiple forms, diagrams, tables, physical mock-ups, or drawings, provided it serves to describe, explain, and predict the phenomenon under study (Oliva, 2019).

This approach is particularly powerful in school contexts because it enables work with progressively more complex models that are close to students' initial ideas yet oriented toward more rigorous explanations. Thus, instruction is organized around cycles of model construction, comparison, revision, and application, rather than the transmission of closed definitions (Soto & Couso, 2023). In this sense, structuring learning around models offers a plausible pathway to re-channel alternative conceptions without dismissing them, integrating them instead as a starting point within conceptual progression trajectories (Oliva, 2019).

Analogies play a prominent role within model-based teaching because they help students imagine, visualize, and reason about unobservable entities and complex processes, and they support the organization of knowledge through provisional versions of the model prior to application (Harrison & Treagust, 2006; Jorba & Sanmartí, 1996). However, their effectiveness depends on the teacher's guidance, explicit or otherwise, in helping students recognize both the similarities and the limitations between the analogy and the target phenomenon (Harrison & Treagust, 2006). For the greenhouse effect, carefully designed analogies can anchor core ideas such as radiative balance, absorption/reflection, and its natural regulatory role in maintaining the planet's temperature (Eriksson et al., 2024).

Methodology

Participants

A total of 131 participants residing in the province of Cádiz (Spain) took part in this study: 74 students in 3rd and 4th grades of middle school, 11 students in 1st grade of high school, 39 Master's students (8 from the Master's in Aquaculture and Fisheries, and 31 from the Master of Education), and, finally, 7 in-service teachers at the high school, and university levels.

To explore the presence and persistence of alternative conceptions across educational stages, participants were grouped into two cohorts: Group 1 comprised the 85 middle and high school student participants, and Group 2 comprised the 46 university-level participants (Master's students and practicing teachers). This study forms part of a broader research project aimed at designing, implementing, and evaluating a teaching–learning sequence on the regulation of the planet's climate. In this phase, the analysis focuses on validating a construct map; consequently, the groups were not balanced a priori in the initial design. The configuration of this particular study was established post hoc, once the data had been analysed and the persistent ideas to be characterized in greater depth had been identified.

Instrument

A validated open-ended questionnaire (Brenes-Cuevas et al., 2024) was used as the data collection instrument, consisting of four questions. These questions were designed to address different factors regulating the Earth's climate, such as global ocean circulation, atmospheric circulation, and the greenhouse effect. The present study focused exclusively on the question related to the greenhouse effect: *"What is the greenhouse effect? Why does it occur? Explain it in your own words and represent it using the following diagram."*

Data Analysis Procedure

A construct map was developed and validated to analyse the responses related to each of the factors regulating climate. However, as previously mentioned, the present study focuses specifically on one of the dimensions of this construct map, that corresponding to the greenhouse effect (Table 1).

To address the aim of this study, analysing participants' conceptions of the greenhouse effect, a three-phase analytical procedure was applied. In the first phase, responses were classified according to the levels defined in the construct map (Table 1), with the objective of identifying the overall frequency distribution.

Table 1. Greenhouse effect dimension of the construct map.

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 3
Trivial or blank responses.	Identifies the greenhouse effect as a phenomenon occurring in the atmosphere, possibly mentioning the absorption and/or reflection of solar radiation. Does not clearly define the process and/or interprets it as synonymous with other phenomena (climate change, ozone layer, etc.). Makes no reference to its nature (neither as a natural phenomenon regulating the climate nor as an anthropogenic factor).	Identifies the greenhouse effect as the phenomenon of absorption and/or reflection of solar radiation in the atmosphere, without reference to other phenomena (climate change, ozone layer, etc.), but does not clearly define the process. Makes no reference to its nature (as a natural phenomenon regulating the climate), or attributes it exclusively to anthropogenic factors with negative consequences for the planet.	Identifies the greenhouse effect as the phenomenon of absorption and reflection of solar radiation in the atmosphere, possibly without clearly defining the process. Refers to its positive nature as a regulatory factor of the climate, potentially recognizing it as an essential factor for life.

Subsequently, in the second phase, the set of responses corresponding to participants classified at Level 2 was analysed in greater detail. An emergent system of non-exclusive categories was established to characterize the responses and examine frequency distributions, given the high number of participants identified at this level, as will be discussed in the following section. The resulting categories were:

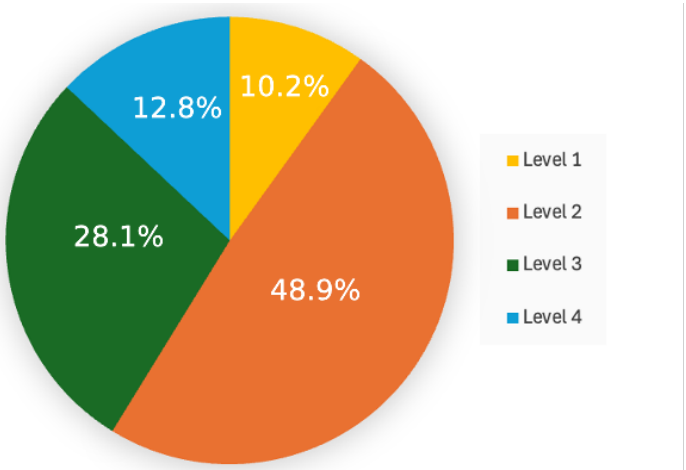
- Atmospheric phenomenon: Participants identify the greenhouse effect as a phenomenon that occurs in the atmosphere.
- Phenomenon functioning: Participants mention the absorption and/or reflection of solar radiation.
- Nature of the phenomenon: Participants identify the greenhouse effect as either a natural or an anthropogenic phenomenon.
- Ozone layer: Participants associate the ozone layer as part of the greenhouse effect.
- Climate change: Participants identify the greenhouse effect as synonymous with climate change.
- Other: This category includes other low-frequency alternative conceptions that are not trivial enough to be classified under Level 1.

Finally, in the third phase, the frequency of these categories was compared between the two groups of participants classified at Level 2, differentiated by educational level: Group 1 (middle and high school students) and Group 2 (participants with university studies). The aim was to analyse the persistence of alternative conceptions across educational stages.

Results And Discussion

Following the established sequence of analysis, the first phase consisted of classifying the responses about the greenhouse effect according to the levels defined in the construct map (Table 1). The analysis revealed a distribution of participants' ideas across all levels (Figure 1), showing a similar percentage (around 10%) at Levels 1 and 4. However, the most representative level was Level 2, accounting for 48.9% (64 out of 131 participants). These participants understood the greenhouse effect as a phenomenon occurring in the atmosphere but did not clearly define the process and/or interpreted it as synonymous with other phenomena, such as climate change or the ozone layer, without referring to its nature. For this reason, Phase 2 of this study focuses on the distribution and categorization of these ideas.

Fig. 1. Distribution by levels of participants' responses about the greenhouse effect.



In the second phase of the study, the responses of the 64 participants classified at Level 2 were analysed in detail according to the categorization described in the previous section. The results show, first, that 93.8% of the participants at this level (60 out of 64) identified the greenhouse effect as an atmospheric phenomenon. However, this identification was not always accompanied by complete explanations of how the phenomenon operates (Figure 2).

Figure. 2. Example of a participant's representation at Level 2.

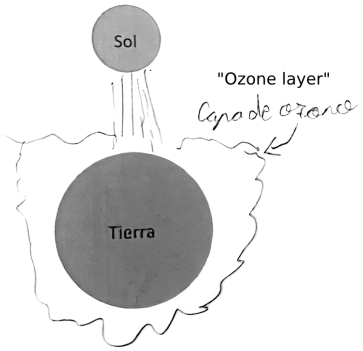
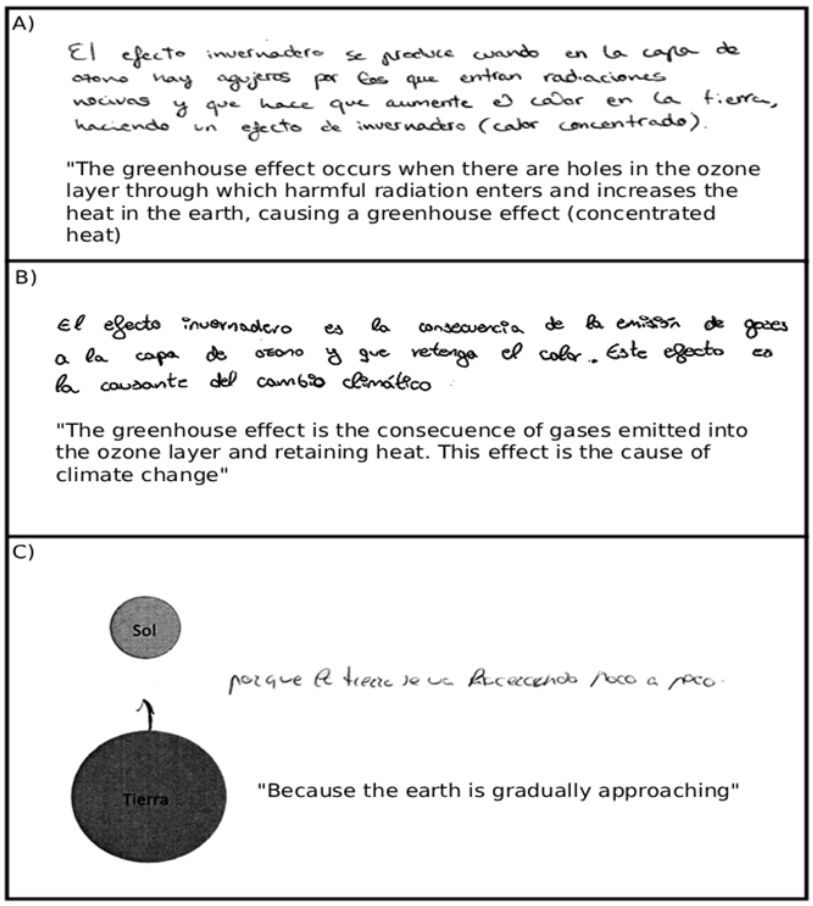


Figure. 3. Example of Level 2 participants' responses classified into different categories. a) Ozone layer, b) Climate change, and c) Other.



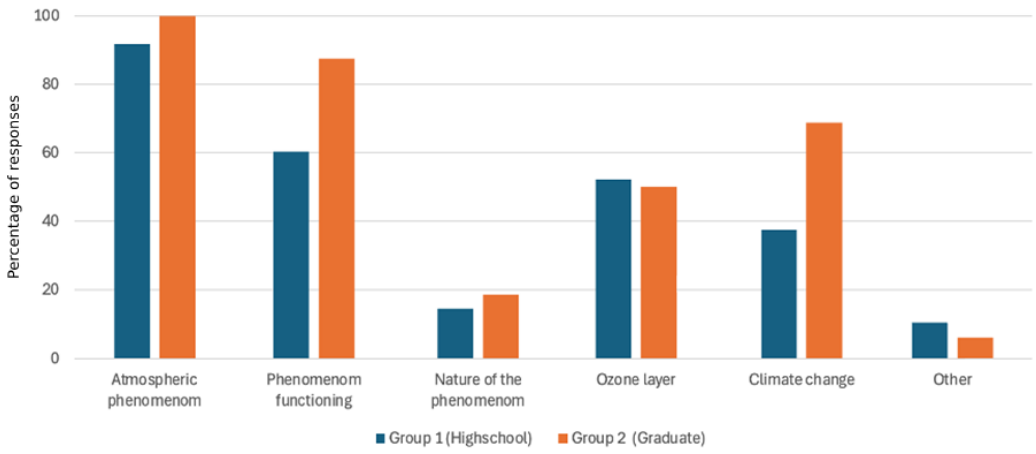
Regarding the functioning of the phenomenon, 67.2% of participants (43 out of 64) mentioned that the greenhouse effect involves the absorption and/or reflection of solar radiation. Despite this, it is noteworthy that the category "Nature of the phenomenon" shows an absence of reference to the natural character of the greenhouse effect in 54 out of 64 participants (84.4%). Likewise, in the "Ozone layer" category, 33 participants (51.6%) associated this element as part of the greenhouse effect. Finally, confusion between the greenhouse effect and climate change was

observed in 23 responses (35.9%), while 6 of the 64 participants (9.4%) provided answers included in the "Other" category (Figure 3).

Finally, in the third phase of the analysis, with the aim of examining the persistence of alternative conceptions across different educational stages, the responses of participants classified at Level 2 of the construct map from the previous phase were separated according to their educational level. The first group consisted of middle and high school students, while the second group included participants with university studies. The frequencies obtained for each category were compared between the two groups.

Figure 4 presents the results of this analysis. It can be observed that all university-level participants (100%) (Group 2) identified the greenhouse effect as an atmospheric phenomenon without clearly defining the process, which is why they are placed at Level 2 of the construct map. Similarly, although with a slightly lower percentage (91.6%), middle and high school student participants (Group 1) also mentioned this category at this level.

Fig. 4. Percentage of responses according to the Level 2 categorization for both participant groups. Non-exclusive categories.



Furthermore, 88% of Group 2 participants mentioned that the greenhouse effect involves the absorption and/or reflection of solar radiation, while only 60% of Group 1 participants expressed this idea. This suggests a greater ability to describe specific physical aspects of the phenomenon at more advanced educational stages, which seems logical given their training. However, both groups showed similar percentages of responses that did not reflect an understanding of the nature of the phenomenon, 85.4% in Group 1 and 81.3% in Group 2. In other words, only 14.6% and 18.7%, respectively, identified the greenhouse effect as a natural or anthropogenic phenomenon, revealing an incomplete understanding of the phenomenon at both educational levels.

Regarding alternative ideas, the results show that a similar percentage of participants in both groups considered the ozone layer to be part of the greenhouse effect, 52% in Group 1 and 50% in Group 2. These findings suggest that this alternative conception persists even at advanced educational stages. However, confusion between climate change and the greenhouse effect was more prevalent among university students (68.8%) than among middle and high school students (37.5%). This finding highlights the complexity that university-level participants face when differentiating between related climatic phenomena or elements, despite their advanced education. It also shows that, while alternative conceptions are present in both groups, the characteristics of each educational stage influence the type of ideas expressed.

In the case of university students, this tendency may be explained by deeper but fragmented knowledge, which allows them to recognize the relationship between the greenhouse effect and

climate change. However, they fail to clearly distinguish the nature of the former as a natural phenomenon, in contrast to the anthropogenic increase in greenhouse gases that intensifies this effect and contributes to climate change. This partial understanding may lead to associations with other atmospheric elements, such as the ozone layer (Roßbegalle & Ralle, 2016). Conversely, middle and high school students, having less structured knowledge, tend to provide simpler and shorter explanations, which reduces associations between phenomena, although this does not imply stronger understanding, but rather lower conceptual complexity (Shepardson et al., 2011).

Alternative conceptions related to the ozone layer and climate change persist over time, consistent with the findings of Sakarya et al. (2023), who conducted a study with Master's students in Environmental Education. This pattern of alternative conceptions across different educational stages confirms the need for model-based teaching that promotes the integration and articulation of the various atmospheric phenomena and components.

In order to improve educational practice and in line with the results obtained, it is proposed to integrate analogies within model-based teaching–learning sequences to facilitate the shift toward Level 3 or 4 explanations, in which students cease to associate these phenomena indiscriminately and begin to recognize the greenhouse effect as a natural process regulating the climate. Analogies, by involving the comparison between elements of the target phenomenon and those of the model, make it possible to identify both the similarities and the differences between them. This comparative process helps distinguish the mechanisms characteristic of each phenomenon or element, fostering a more structured and accurate understanding of the processes involved. In this case, it enables comprehension of the natural greenhouse effect as a physical process of infrared radiative energy balance, while the ozone layer acts as a UV filter, without intervening in this balance (Harrison & Treagust, 2006). In this way, analogies serve as cognitive anchors that help students establish clear conceptual boundaries, supporting the construction of mental models and a more precise interpretation of atmospheric processes (Eriksson et al., 2024).

Conclusions

This study analysed participants' conceptions of the greenhouse effect, identifying alternative conceptions that persist across different educational stages, even among students at higher levels. The results reveal difficulties, particularly in differentiating between the greenhouse effect and concepts such as the ozone layer and climate change. Although the university-level participants in this study demonstrated a greater ability to integrate technical aspects, such as the reflection and absorption of solar radiation, other alternative conceptions persist, such as viewing the ozone layer as part of the greenhouse effect, which hinders the achievement of the reference school-science model.

These findings highlight the need to implement educational strategies that address these difficulties from early stages, designing teaching–learning proposals that promote a clear and precise differentiation of these concepts (Andersson & Wallin, 2000). Model-based teaching strategies and the use of modelling resources may be effective approaches to this end (Papadimitriou, 2004). In this regard, the use of carefully selected analogies, guided by the teacher, is understood as a viable option to facilitate the understanding of the physical processes involved (Harrison & Treagust, 2006; Eriksson et al., 2024).

Acknowledgement

Funded by the Ministry of Science and Innovation—Knowledge Generation Projects/Project PID2022-136353NB-I00.

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Assessing Climate-Change Competence in Pre-Service Teachers: Knowledge, Attitudes, and Behavioural Engagement in Climate Education

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The effects of accelerated climate change on nature and society are evident, primarily driven by human-induced greenhouse gas emissions, causing severe and often irreversible damage. Despite scientific consensus, climate change denial has increased, particularly among far-right political groups, hindering mitigation efforts and heightening societal uncertainty. Education plays a crucial role in addressing this challenge by fostering climate literacy, equipping individuals with knowledge, skills, and attitudes necessary for action. The Climate-change Competence (C3) framework was introduced to assess climate literacy in education, later refined to evaluate pre-service teachers in different countries, emphasizing its role in shaping future societal responses. This study seeks to assess the level of climate-change competence among pre-service teachers at Universidad Complutense de Madrid, contextualizing the C3 framework within their specific educational environment. Our findings align with previous research, indicating that pre-service teachers in Madrid demonstrate high levels of climate- change competence, particularly in knowledge and attitude dimensions. They recognize the causes and consequences of climate change and express a proactive stance toward mitigation. However, their commitment to concrete actions remains moderate, especially in areas related to food and diet. No significant differences were found based on academic background or gender, except in attitudes, where undergraduate and female students showed greater commitment. These results reinforce the need to strengthen behavioural engagement strategies in climate education to enhance real-world action

Keywords: Climate Change Competence, Pre-Service Teachers, Spain

Introduction

Context And Theoretical Framework

The impacts of accelerated climate change on natural systems and human societies are indisputable (Wheeler and Von Braun, 2013; Dao et al., 2023; Abbass et al., 2022). In its most recent report published in 2023, the Intergovernmental Panel on Climate Change (IPCC) has reaffirmed the anthropogenic origin of global warming, primarily driven by greenhouse gas emissions, which is leading to significant, and in some cases irreversible, damages and losses. However, despite the scientific consensus confirming accelerated climate change as a factual phenomenon, climate change denial has intensified in recent years (Washington and Cook, 2011; Dunlap & Brulle, 2020). In this context, far-right parties and political actors are increasingly promoting denialist narratives regarding the consequences of climate change (Gruber, 2025), hindering the adoption of mitigation measures, complicating efforts to alleviate current impacts, and increasing societal uncertainty (Wong-Parodi and Feygina, 2019).

Nevertheless, governments have access to a broad range of policies and strategies to address climate change. Among the various actions aimed at mitigating its effects, education emerges as a central element for enhancing knowledge, skills, and attitudes in response to the social and environmental challenges posed by climate change. Numerous studies highlight the importance of climate change literacy as a key tool to confront this issue effectively (Johnston & Cook, 2019; Nusche et al., 2024). Given their pivotal role within educational systems, teachers constitute one

of the fundamental pillars for fostering climate change literacy among students, who are future citizens and among those most vulnerable to climate change impacts. However, there is currently no clearly defined approach or legislative framework to systematically guide the implementation of this educational responsibility across different states.

To begin developing a strategy that positions education as a driving force for societal mobilisation, it is essential to assess the extent to which current educational systems prepare students to understand climate change, raise awareness, and promote action (Fuertes et al., 2020). In their seminal work, Fuertes et al. (2020) introduced the concept of Climate Change Competence (C3), defined as a "framework to develop understanding, awareness and abilities related to Climate Change through Education", enabling individuals to effectively address the global crisis through formal education. Subsequently, Ferrari et al. (2022) operationalised this competence by defining three distinct dimensions through a validated assessment questionnaire comprising 36 items, administered to a sample of over 500 primary and secondary school teachers. More recently, these dimensions were revised and adapted for pre-service teachers in Honduras and Spain using an updated set of items (Ferrari et al., 2024).

Aims Of The Research And Hypothesis

This study aims to determine the degree of climate-change competence of the pre-service teachers from the Universidad Complutense de Madrid (Madrid, Spain), defining the C3 competence in their context.

In the Spanish context, pre-service teachers are trained within higher education programs that increasingly acknowledge sustainability and climate change, yet research consistently shows important gaps between curricular intentions and actual competences. Previous studies indicate that Spanish pre-service teachers tend to display limited and fragmented environmental and climate-related knowledge, while simultaneously expressing generally positive attitudes, a sense of responsibility, and a moderate level of pro-environmental behaviour (Álvarez García et al 2018). This imbalance suggests that favourable dispositions towards environmental issues are not always accompanied by sufficiently robust conceptual understanding or by a strong capacity to translate concern into effective educational practice. Moreover, recent evidence highlights the central role of affective dimensions in this context (Ballegeer et al, 2024; Fuertes-Preito, et al, 2024). Subject-matter knowledge alone does not directly predict pre-service teachers' willingness to engage in climate change education, but rather exerts an indirect influence mediated by attitudes and emotional engagement. Emotions related to climate change appear to act as key activating or inhibiting factors, shaping both mitigation-oriented behaviours and the intention to include climate change in future teaching. In fact, Spanish pre-service teachers can be broadly characterized into distinct profiles, ranging from more "concerned" individuals, who show higher levels of climate-change competence and a stronger willingness to act as educational change agents, to more "sceptical" ones, who exhibit lower competence and reduced engagement. Taken together, this body of research suggests that the specific context of Spanish pre-service teachers is defined by a combination of insufficient knowledge, generally positive but unevenly operationalized attitudes, and emotionally driven dispositions that critically condition their readiness to teach about climate change.

Table 1. Resume of the subdimensions conforming the dimensions of the C3 competence, including the mean values for each subdimensions and dimensions of the students included in the analyses. D: dimensions; n: number of variables included in the analyses; T: Whole dataset; Dg: Degree; Ms: Master; M: Male; F: Female.

D	Sub-D	n	Definition	Mean Sub-Dimensions					Mean Dimensions		
				T	Dg	Ms	M	F	T	Dg Ms	M F
KNOWLEDGE	BPP	3	Biophysical Processes	4,10	4,10	4,08	4,20	4,08	4,12	4,10 4,16	4,18 4,10
	CAU	6	Causes	4,15	4,14	4,20	4,25	4,13			
	CQS	4	Consequences	4,47	4,48	4,45	4,43	4,48			
	MIT	5	Mitigation	3,80	3,77	3,92	3,90	3,78			
ACTION	MAC	2	Consumption	3,44	3,45	3,38	3,44	3,44	3,32	3,32 3,35	3,37 3,31
	TRA	2	Transportation	3,55	3,54	3,60	3,70	3,53			
	ESA	2	Energy saving	3,55	3,97	4,14	4,08	3,99			
	F&D	2	Food and Diet	2,31	2,31	2,29	2,27	2,31			
ATTITUDE	CON	5	Concern	4,40	4,42	4,31	4,22	4,43	4,07	4,09 3,98	3,94 4,09
	LOC	5	Personal efficacy to act	3,82	3,88	3,55	3,54	3,87			
	HOP	4	Hope	3,73	3,76	3,61	3,63	3,75			
	WTT	3	Willingness to teach	3,90	3,86	4,06	3,96	3,88			
	EDR	5	Actions on Schools	4,37	4,38	4,30	4,24	4,39			
	POL	5	National Policy support	4,06	4,08	4,01	3,99	4,07			

Research Methodology Design And Materials.

Following the methodology described by Ferrari et al (2022), and considering the adaptations proposed by Ferrari et al (2024) where the main dimensions and subdimensions of the Climate-Change Competence (C3) were redefined (table 1), the climatic competence of preservice teachers from the Comunidad de Madrid (Spain) was determined. By means of a closed-ended Likert-scale test formed by 53 questions (Ferrari et al., 2024), with five response categories (from false/never/totally disagreed to true/always/totally agreed), the C3 competence spectra was defined for a total of 316 students from six different degrees, all pertaining to the Facultad de Educación – CFP (Universidad Complutense de Madrid). The mean values of the whole set of questions defining the subdimensions of the climate competence spectra were calculated, together with the means for the dimensions.

In order to determine if gender or university background condition the C3 competence spectra, U-Mann Whitney (non-parametrical) and T-Student (parametrical) analyses on C3 competence dimensions were performed (depending on the distribution of the data groups).

Results

Tables 1 (previous page) and 2 resume the results for these analyses defining C3 competence spectra of preservice teachers from the Universidad Complutense de Madrid and its relationship with gender and university background.

Table 2. Results of the statistical analysis to compare C3 competence dimensions between students from different university backgrounds and between genders.

		n	KNOWLEDGE		ACTION		ATTITUDE	
			Mean	Statistics	Mean	Statistics	Mean	Statistics
University background	**Degree**	259	4,11	p = 0.289 U = 1.059	3,32	p = 0.590 U = 0.590	4,09	**p = 0,048** **T = 1.681**
	Master	57	4,16		3,35		3,98	
Gender	**Male**	44	4,18	p = 0.096 U = -1.667	3,38	p = 0.403 U = -0.837	3,94	p = 0.055 T = -1.629
	Female	271	4,10		3,32		4,09	

Discussion

Our results are aligned with those exposed by Ferrari et al (2022) and (2024), with relatively high values for all three dimensions of the Climate-change competence. Pre-service teachers from Madrid demonstrate an adequate capacity to identify the principal causes and consequences of climate change (mean scores for knowledge dimensions and subdimensions close to 4, reflecting agreement with the test items and statements), and they also display a proactive stance towards addressing climate change (mean values for attitude dimensions and subdimensions near 4, indicating agreement with the proposed actions included in the questionnaire). However, in line with previous research on climate change mitigation behaviours among both pre-service and in-service teachers (Seroussi et al., 2019; Banos-Gonzalez et al., 2021; Tolppanen et al., 2021), our results reveal a moderate level of commitment regarding the actions undertaken to reduce the

causes and impacts of climate change (mean values for action dimensions and subdimensions around 3.5, suggesting partial engagement in climate action), with behaviours related to food choices and dietary habits obtaining the lowest scores. Conversely, no significant differences were observed in C3 competence according to university background or gender, apart from the attitude dimension, in which undergraduate students showed a higher level of commitment to combating climate change than postgraduate students

These patterns are evident not only when analysing the full sample, but also when considering university background and gender, with consistently higher scores in the knowledge and action subdimensions. No statistically significant differences were found (results not shown) across most subdimensions between undergraduate and postgraduate students, nor between males and females, except for LOC and WTT, which did show significant differences. However, minor variations can be identified in the attitudinal subdimensions. Overall, these findings are consistent with previous research on climate change awareness influenced by academic background and gender (Clayton et al., 2023). In general, undergraduate students obtained higher scores than master's students, reflecting a more proactive attitude towards addressing the causes of climate change. A plausible explanation for this pattern is that the more advanced and specialized training of master's students may be associated with a higher level of critical awareness, scepticism, and a deeper understanding of the structural limitations, uncertainties, and shortcomings of many climate change mitigation actions implemented in practice. This greater recognition of complexity may, in turn, reduce their perceived efficacy and willingness to adopt a proactive stance. The same difference can be observed for male and female students, where women are more willing to take action to preserve the environment.

Conclusions

Our findings shown that pre-service teachers from Madrid exhibit relatively high levels of Climate-change competence, particularly in knowledge and attitude dimensions. They recognize the causes and consequences of climate change and express a proactive stance toward mitigation. However, as observed in previous studies, their actual commitment to climate action is moderate, with lower engagement in behaviours related to food and diet.

No significant differences were found in Climate-change competence across academic backgrounds or gender, except in the attitude dimension, where undergraduate students displayed greater commitment than postgraduates. Similarly, female students showed a higher willingness to act than males, consistent with prior studies. These results reinforce the importance of integrating behavioural engagement strategies in climate education.

Following the exploration of Climate-change Competence (C3) among pre-service teachers (PSTs) at the Facultad de Educación – CFP of the Universidad Complutense de Madrid (UCM), future research aims to further investigate this competence in relation to didactic variables that reflect PSTs' concerns regarding Climate Change Education. This study will extend beyond the Comunidad de Madrid, incorporating samples from other Spanish regions as well as countries such as Honduras.

Acknowledgement

Authors would like to thank to the students who participated in this research. This research was supported by the research groups UCM-910607, on Evolution of Cenozoic Mammals and Continental Palaeoenvironments, and UCM-970826, on Ecology and Environmental Education at the School. This work was also supported by research projects PGC2018-094955-A-I00 y PID2022-138275NB-I00 from the Ministerio de Ciencia, Innovación y Universidades.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Students' Misconceptions About Heatwaves And Their Interconnection With Climate Change

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The increasing frequency and severity of heatwaves globally highlights the urgency of integrating this pressing issue into education. Providing future generations with the knowledge to comprehend the science behind heatwaves and their relationship to climate change is essential. Such knowledge empowers students to adapt effectively, develop resilience, and acquire skills necessary for a sustainable future. This study assesses school students' perceptions and knowledge of heatwaves among secondary students from Belgium, Greece, Italy and Romania. A quantitative approach was employed, with data gathered through a questionnaire (N=392). The findings reveal that while some students have basic understanding of heatwaves, significant misconceptions persist, particularly concerning the connection between heatwaves and climate change. Furthermore, many students cannot directly decide the relation between heatwaves and health risks. These results underscore the need for targeted educational interventions. By enhancing students' understanding of the causes and effects of heatwaves, educators can foster a more engaging and impactful learning experience. These efforts are crucial for enhancing preparedness and creating a generation better equipped to tackle climate change challenges.

Keywords: Environment, Science Education, Sustainability

Introduction

Heatwaves pose a growing natural hazard with severe consequences for human health, ecosystems and infrastructure (Murray et al., 2012). Despite the scientific consensus on the interconnectedness of climate change, global warming, and heatwaves, pervasive misconceptions continue to endure (Bostrom et al., 1994). These misconceptions encompass a lack of clarity regarding the relationship between heatwaves and climate change confusion surrounding the mechanisms that cause heatwaves (Williams et al., 2019), underestimation of the health hazards posed by heatwaves, and a widespread deficiency in knowledge about proactive measures for heatwave preparedness (Lampl et al., 2023). These arise from complex factors, hindering public understanding and response such as, (a) limited scientific literacy (Chowdhury et al., 2012), (b) representations in the media (Perkins, 2015), (c) personal experience bias (Ruth et al., 2019), (d) information overload and fatigue (Perkins, 2015), (e) lack of trust in authorities (Chowdhury et al., 2012).

The need for targeted public education campaigns that emphasize the dangers of heatwaves and provide clear guidance on risk abatement and preparedness strategies is evident (Yepéz et al., 2019). By incorporating the issue of heatwaves into school curricula, we foster climate literacy to make informed decisions and advocate for effective mitigation and adaptation strategies (VanderMolen et al., 2022). Understanding students' existing perceptions of heatwaves, including their potential misconceptions, is important for designing targeted educational interventions that foster scientific knowledge and promote responsible environmental stewardship (VanderMolen et al., 2022). Based on the above, we considered it valuable to investigate whether school students are aware of the widespread presence of heatwaves and their associated health risks. The research questions guiding our study are:

(R.Q.1) How do students self-report their level of environmental awareness ?

(R.Q.2) How well are students informed about (a) the prevalence of heatwaves and (b) the associated health risks, while interrelated with climate change, across the countries of the research?

(R.Q.3) What is the relationship between students' self-reported environmental awareness and experience of teaching with their perceived knowledge of heatwaves and their interconnection with climate change?

Materials And Methods

To address the above-mentioned questions, we conducted quantitative research involving N=392 students (grades 5–8) from Belgium, Greece, Italy and Romania. The participants were selected through convenience sampling, with their age and gender distribution shown in Table 1. Both ethical approval and license were obtained to conduct the research.

Table 1. Age and gender of the sample per country and in total.

		Country				
		Belgium N=62	**Greece N=120**	**Italy N=70**	**Romania N=140**	**Total N=392**
Age	mean±SD	13.77±0.15	12.55±0.07	12.81±0.167	15.62±0.14	13.69±0.13
Gender	Male N(%)	30(48.4)	59(49.2)	39(55.7)	84(60.0)	212(54.1)
	Female N(%)	32(51.6)	58(48.3)	31(44.3)	56(40.0)	177(45.2)
	Other N(%)	-	3(2.5)	-	-	3(0,7)

A 31-item questionnaire was developed and distributed online to students via Google Forms during the November of 2023, to evaluate their knowledge of heatwaves, including their prevalence and associated health risks. The questionnaire has been based on insights from relevant literature (Arslan et al., 2012; Cheng et al., 2019; Fernandez et al., 2015; Huang et al., 2011; Macintyre et al., 2018; Koutra-Heliopoulou et al., 2023; Meehl & Tebaldi, 2004). Besides questions about the profile of the sample (6 items addressing age, country, grade, gender, environmental awareness, and students' teaching experiences), 25 5-point Likert scale items (1=totally disagree to 5=totally agree) focused on:

(a) *General Knowledge* about heatwaves (GK) (C1-C16) including heatwaves' prevalence, and their interconnections with climate change,

(b) *Health Knowledge* (HK) about Heatwaves and their associated health-risks (C17-C25). Negatively worded items were reversed so that scores ranged from 1 (low knowledge) to 5 (high knowledge).

It is important to clarify that the item on students' teaching experiences referred to any formal lessons, workshops, or classroom discussions students had received about heatwaves, climate change, or related environmental topics.

The reliability of the instrument and the two subscales was estimated based on Cronbach's alpha and the results were considered moderate and acceptable (Nunnally, 1978; Taber, 2018) (Table 2).

Table 2. The questionnaire's and subscale's reliability.

Subscale	Cronbach's Alpha	Items
General_ Knowledge about heatwaves	.695	8
Health_ Knowledge about heatwaves	.612	17
Total	*.740*	*25*

Results

Students self-reported a medium level of environmental awareness (3.48±0.87), and a low level of exposure in heatwaves teaching (1.58±0.49), which varied significantly across the countries (F=15.646, p<.001). Students from Italy have received the most extensive teaching about heatwaves (=1.91±0.28) compared to the others.

They demonstrate a medium level of knowledge about heatwaves and their health-related issues (Health Knowledge – HK), as well as their prevalence and connections to climate change (General Knowledge – GK), However, scores differ significantly between countries (Table 3), with students from Greece and Romania showing the highest levels.

Table 3. Students' knowledge about heatwaves.

	Belgium	Greece	Italy	Romania	Total
Health _ Knowledge*	3.26±0.306	3.63±0.695	3.34±0.438	3.61±0.712	*3.52±0.635*
General _ Knowledge**	3.00±0.304	3.48±0.459	3.08±0.343	3.40±0.420	*3.30±0.444*

*F=7.209, p<.001, **F=25.65, p<.001.

Going deeper on students' answers (Table 4) regarding their General Knowledge of heatwaves, our findings show that 53.9% of students recognize the link between climate change and heatwaves (Q5) and 56.4% of students recognize that climate change makes heatwaves more frequent and intense (Q3), whereas only 22.2% are aware of the broader economic impacts of heatwaves on European cities, such as reduced productivity and tourism (Q10).

Regarding students' Health Knowledge of heatwaves (Table 4), the data reveal significant gaps. Only 49.5% of students correctly associate extreme heat with heat-related illnesses (Q22). Furthermore, 46.9% identify excessive sweating as a sign of heat stress (Q23) and only 55.8% of students recognize that individuals with heart problems are more vulnerable during heatwaves (Q24). However, 49.6% understand that the elderly and young children are more susceptible (Q25), showing that nearly one-fifth may not fully grasp the disproportionate risks for these groups.

Table 4. Students' distribution of answers in each item regarding their knowledge about heatwaves.

Questions	Disagree*	Neutral	Agree
General Knowledge			
Climate change is making heatwaves less frequent and less intense.	32.6%	32.4%	34.9%
Climate change is making heatwaves more frequent but less intense.	36.4%	36.5%	26.5%
Climate change is making heatwaves more frequent and more intense.	17.6%	26.0%	56.4%
Climate change is making heatwaves less frequent but more intense.	34.3%	36.1%	29.6%
Climate change has no connection to heatwaves.	53.9%	24.6%	21.5%
Heatwaves do not affect European cities differently from other regions.	35.1%	35.3%	29.6%
Heatwaves can lead to an increase in air pollution in European cities.	15.8%	29.9%	54.2%
Heatwaves can cause an increase in energy demand and strain on the power grid in European cities.	16.1%	36.8%	47.0%
Heatwaves can cause negative health impacts for vulnerable populations in European cities.	14.6%	31.2%	54.2%
Heatwaves can lead to economic impacts such as decreased productivity and tourism in European cities.	18.6%	34.5%	49.9%
Heatwaves can exacerbate the urban heat island effect in European cities.	17.7%	42.4%	39.9%
Heatwaves affect cities the same way across Europe.	33.2%	31.6%	35.2%
Sprinklers in open grounds and fans can play a role in cooling.	20.7%	41.6%	37.8%
Creating forests within cities and green corridors are an effective way to shift airmass to cool large areas within a city.	17.3%	32.3%	50.4%
If you wear dark clothes you feel cool in summer.	55.4%	23.3%	21.3%
Windows and doors should be opened at noon on hot days.	36.8%	28.9%	34.2%
Health Knowledge			
Fever, fatigue, and chest tightness are common symptoms of heat stroke.	16.3%	35.5%	48.2%
Some medicines can increase the risk of heatstroke.	23.8%	38.6%	37.6%
High environmental temperature can cause death.	14.6%	31.9%	53.5%
Heat waves are caused by high temperature and low rainfall.	15.8%	29.4%	54.8%
Extreme heat exposure is responsible for heat-related illnesses.	16.8%	33.7%	49.5%
Excess sweating during a heat wave can be a sign of heat stress.	14.9%	38.1%	46.9%
Individuals suffering from heart problems are highly vulnerable during a heatwave.	13.6%	30.6%	55.8%
The elderly and young ones are more vulnerable during a heat wave.	18.1%	32.3%	49.6%
The greenhouse effect is mainly caused by the depletion of the ozone layer.	17.6%	40.1%	42.3%

Students' environmental awareness and teaching experience show a very low but statistically significant correlation with HK and GK (r= .147, r=.005) (r= .134, r=.011).

Discussion

Our results highlight gaps in heatwave education despite students reporting a moderate level of environmental awareness. The findings reveal notable differences in students' environmental awareness across countries, reflecting disparities in the prioritization of heatwave education. These variations may stem from differences in national curricula, the perceived local relevance of heatwaves, or broader environmental education policies, issues that merit further exploration. Greece and Romania demonstrated higher, though still moderate, levels of knowledge, suggesting either a stronger educational emphasis or more extensive public awareness initiatives. However, additional research is needed to substantiate these interpretations. Targeted educational interventions may be particularly beneficial for Belgium and Italy, where students' understanding appears more limited.

Students' knowledge about heatwaves also varied substantially. Many were unaware of the broader economic consequences of heatwaves on European cities, indicating a need for more comprehensive climate education that addresses both direct and indirect impacts. Only about half of the participants correctly associated extreme heat with heat-related illnesses or recognized excessive sweating as a symptom of heat stress, findings that reinforce earlier calls (Knowlton et al., 2009) for more systematic education on the health dimensions of heat exposure. As Hajat et al. (2014) emphasized, the lack of recognition of heat stress symptoms can delay appropriate responses, thereby increasing health risks.

Furthermore, nearly one-fifth of students did not fully grasp the disproportionate risks that heatwaves pose for vulnerable populations such as the elderly, young children, and individuals with pre-existing health conditions. The weak correlation between students' environmental awareness, teaching experiences, and their knowledge of heatwaves underscores the need for targeted educational strategies that explicitly link these domains.

Overall, although many students recognize the connection between climate change and heatwaves, significant gaps in understanding remain. Addressing these through focused climate and health education could strengthen students' preparedness, enhance adaptive behaviours, and build resilience to climate-related challenges.

Taken together, future directions in climate change and heatwave education should move beyond the mere transmission of scientific facts toward cultivating students' sense of agency and connection to global environmental challenges. Educational interventions must be intentionally designed to embed these topics within science curricula in ways that are both contextually meaningful and socially relevant. Such approaches should aim to challenge misconceptions, deepen conceptual understanding, and foster adaptive and responsible action. Cross-national research will be essential to continue to explore how diverse educational contexts can sustain these transformative learning experiences, ensuring that education in climate change and sustainability becomes an empowering dimension of students' scientific literacy and civic identity.

Limitations

The small sample size per country limits the generalization of our conclusions to the broader population in the countries researched. At the same time, relying on self-reported measures introduces potential biases like social desirability and recall errors. Additionally, while demographic factors were considered, other relevant variables were not included.

Acknowledgement

(i) The project and its research were undertaken within the scope of the Erasmus+ KA02 initiative under the acronym HEAT (Project Number: 2022-1-EL01-KA220-SCH-000088530 - SR n. 19459). (ii) National Agency for Erasmus+ (IKY), for the support of this funding program.

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First Approaching To Preservice And Inservice Teachers Conceptions About Groundwater

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Meeting the enormous water needs of the human population and the agricultural, industrial and technological sectors is a sustainability challenge recognised by the United Nations. The overexploitation and pollution of aquifers pose a major threat to freshwater availability, especially in a context of climate change and increasing demand. This situation, in addition to being an environmental challenge, represents an educational one: understanding how groundwater systems function is essential for preparing citizens to make informed decisions about water management. This study explores the knowledge of primary and secondary school teachers (78 trainee and practising teachers) about groundwater and aquifers through an exploratory design with quantitative and qualitative analyses. The results show limited knowledge of the concept of aquifers and groundwater, as well as of their distribution and movement. Therefore, there is a need to reinforce and improve teachers' understanding of this topic, given its importance for humanity and ecosystems.

Keywords: Science Literacy, Teacher Beliefs, Groundwater

Introduction

The demand for water has increased exponentially over the last century (Boretti and Rosa, 2019), leading to the overexploitation of aquifers (Andreu Rodes and Fernández Mejuto, 2019), as well as the effects of climate change (Abtew and Melesse, 2013) and pollution (Andreu Rodes and Fernández Mejuto, 2019). Ensuring the availability of water for humanity and ecosystems is therefore considered essential for sustainability and is explicitly reflected in the SDGs. However, several studies have shown that groundwater—the largest reservoir of liquid freshwater on Earth—barely appears in students' representations of the water cycle (Ben-Zvi-Assarf and Orion, 2005a; Pan and Liu, 2018), or appears exclusively as lakes, rivers or underground caves (Ben-Zvi-Assarf and Orion, 2005a; Ben-Zvi-Assarf and Orion, 2005b; Covitt et al., 2009; Unterbruner et al., 2016). Textbooks also show room for improvement in this respect (Reyero et al., 2007; De Pedro Rodríguez & de Soto García, 2023), contributing to the persistence of alternative conceptions.

Teachers play a key role in educating a citizenry that is aware of and responsible for these challenges. However, research on teachers' conceptions of groundwater is scarce, despite its relevance for scientific literacy and sustainability education. This preliminary work therefore seeks to answer the following questions: Do teachers know the quantitative importance of groundwater within total continental liquid water? Do they have an adequate understanding of what an aquifer is and how groundwater behaves?

Methodology

The research has an exploratory scope. Data collection combines quantitative and qualitative approaches through a questionnaire containing open and closed questions. It was administered anonymously at the beginning of several groundwater workshops, meaning that sampling was

non-random and based on convenience. Table 1 shows the questions linked to the research questions posed.

Table 1. Survey questions regarding groundwater.

It marks the percentage represented by groundwater among continental liquid waters <5; 5-20; 20-40; 40-60; 60-90; >90%
What is an aquifer?
Draw how the water is found in the subsoil, take a photograph and upload your drawing here.
How does groundwater move?

A total of 78 individuals participated in the study, providing informed consent: 32 pre-service primary school teachers (PSTP), 31 pre-service secondary school teachers (PSTS) (graduates in Biology, Environmental Sciences, Geology, Geological Engineering and Biochemistry, in decreasing proportion), and 15 in-service teachers (IST), including 8 graduates in Education or other non-scientific fields and 7 with scientific degrees.

Quantitative data analysis focuses on describing the results obtained. Qualitative analysis was conducted using a category system defined inductively through an in-depth reading by the authors (Table 2). The reliability of this system was verified through an inter-observer process in which two researchers applied the category system to a 20% sample of the responses. The resulting coding was subjected to a concordance analysis (Cohen's kappa) using Epidat software. The value obtained (0.849) indicates a high level of agreement (Landis and Koch, 1997). The few discrepancies were resolved among the authors, and the final application of the system was carried out on the full set of qualitative data.

Table 2. Inductively generated system of categories and subcategories.

Category	Subcategory (code)	Description
Definition/representation of aquifers and groundwater	Material capable of holding water	Rock formation or geological material with pores or holes in which water can be stored by infiltration.
	Lake/Pond/River/Place where the water is found in the subsoil	Cavity, stream, or area where groundwater is located
	Reservation/Deposit/Warehouse	Water storage susceptible to exploitation by man
	It is connected to the outside (rivers, sea, sea, etc.).	The water in the subsoil is not stagnant, but communicates with rainwater and/or water from rivers/lakes
Groundwater behaviour	Infiltrates (without specifying where)	Penetrates down
	Moves between pores, capillaries	It penetrates, infiltrates through the gaps in the ground and rocks
	It moves by currents, roads	Similar to rivers or external streams
	Moves (others)	Other factors that condition movement such as gravity, water pressure, tides, etc.
	Unclear/ Don't know/doesn't answer	They do not answer or answers that are difficult to categorize.

Results

The first research question—whether teachers know the percentage of freshwater that groundwater represents within total available continental water—is addressed through the quantitative results of the first questionnaire item. Table 3 shows the results by participant group. Of the total sample, more than 30% believe that less than 20% of continental freshwater is stored underground (mainly among ISTs). Only 3 participants (4.2%) correctly identified the very high relative abundance of groundwater (>90%). Another 14 participants (17.9%) indicated that there is much more groundwater than surface water (PST). Among those who clearly recognised the subsurface as the main reservoir of available water, pre-service teachers stand out.

Table 3. Participants' estimates of groundwater abundance within total continental liquid freshwater.

SUBT WATERS	PSTP (n/%)	PSTS (n/%)	ACTUAL (n/%)	TOTAL (n/%)
<5%	0/0.0	3/9.7	3/20.0	6/7.7
5-20%	7/21.9	8/25.8	3/20.0	18/23.1
20-40%	7/21.9	3/9.7	3/20.0	13/16.7
40-60%	10/31.3	9/29.9	5/33.3	24/30.8
60-90%	6/18.8	7/22.6	1/6.7	14/17.9
>90%	2/6.3	1/3.2	0/0.0	3/3.8

The second research question—whether teachers have an adequate understanding of what an aquifer is and how groundwater behaves—is answered through the qualitative analysis. Regarding the definition of an aquifer, 47.4% associate it with an underground river, lake, stream or cavity, referring to it as "an underground lake". Another 20.5% (mainly PSTS and science-trained ISTs) define it correctly as a material or rock formation with pores that contain water, using expressions such as "a geological formation capable of storing water". A total of 28.2% (across all groups) describe it as a water reserve or reservoir, emphasising its usefulness for humans, e.g., "a water reserve underground". Only a minority (3.8%) mention infiltration from the surface. A single participant (PSTS) refers to the connection between aquifers and rivers from the inside out: "They recharge/discharge into areas such as rivers and lakes and through infiltration".

Regarding groundwater movement, no participant questioned whether groundwater moves. A total of 16.7% compare it to movements similar to those of rivers or surface streams ("through underground channels"). Another 17.9% describe circulation through pores or capillaries in the soil and rocks ("between the pores of the rocks"). Only 10.2% refer to flow velocity, using terms such as "slowly". A total of 24.3% mention factors that may influence movement, such as "pressure differences", "gravity", "capillarity", "following the slope from higher to lower areas", or "filtration". Finally, 3.8% refer to unrelated processes such as "tectonic movements" or "tides".

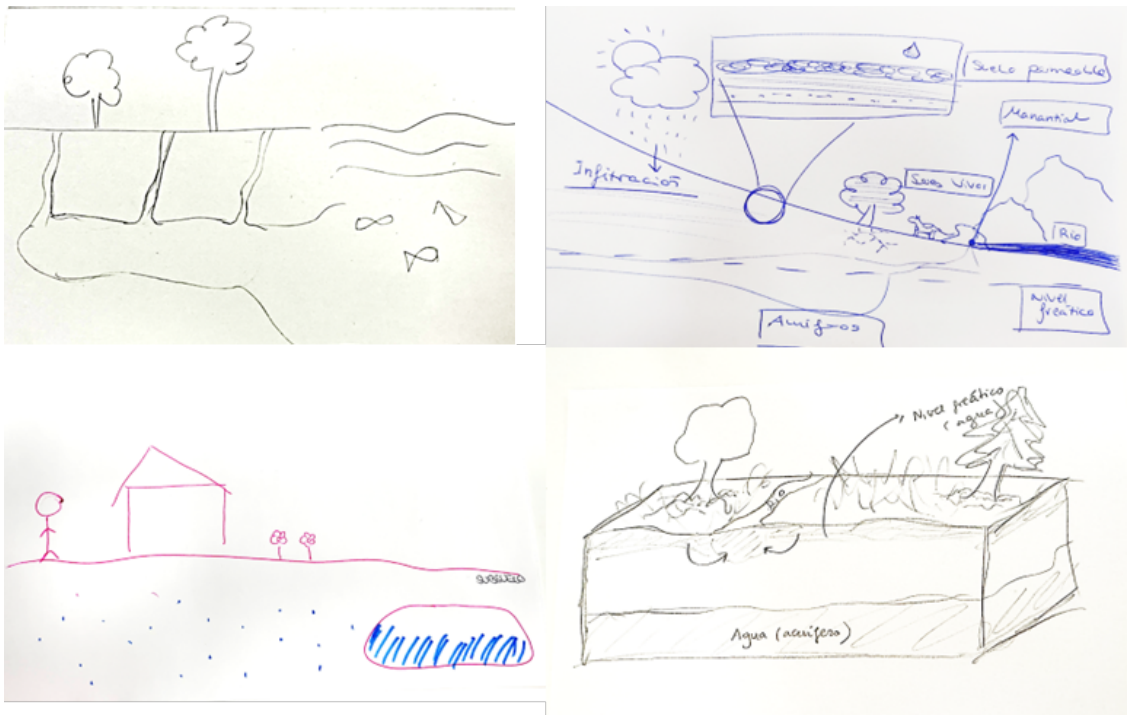
In the drawings, both the representation of groundwater and its connection with the surface and its movement were analysed. Most participants (73.1%) imagined groundwater as underground rivers or pockets (Figures 1a, 1c), sometimes as deep lakes, suggesting that they conceive of groundwater as the lower part of surface water bodies. A total of 21.8%, mainly science graduates, represented porous materials in some detail (sometimes with a magnifying glass), showing water between the pores (Figure 1b). Some drawings were clearly influenced by geology class diagrams, including elements such as the water table, arrows indicating water movement, and specific terminology.

A total of 62.5% of participants represented groundwater as connected to the surface, sea, rivers or springs (Figures 1a, 1b, 1d), while only 5.1% depicted connections from the subsurface to

rivers (winning streams, Figure 1d). Conversely, some drawings showed rivers, ponds or porous layers completely disconnected from the surface (Figure 1c). Only 7% included rainfall (only PSTS), despite it being the main source of groundwater recharge (Figure 1b).

Groundwater movement was represented by arrows or dashed lines in 30.7% of drawings, sometimes labelled as "infiltration" (Figures 1b, 1d). Only 3.8% appear to suggest movement through rock materials. In addition, 13.8% included human use of groundwater, depicting wells.

Figure 1. Drawings showing how participants imagine groundwater. 1a (top left), 1b (top right), 1c (bottom left), 1d (bottom right).



A minority of participants (less than 20%) are aware that groundwater accounts for a much larger volume than surface water. In addition, teachers' understanding of aquifer functioning is quite limited. This is worrying, as it aligns with findings in secondary school students (Ben-Zvi-Assarf & Orion, 2005a; Covitt et al., 2009; Pan & Liu, 2018). PSTS and IST science majors typically offer more precise definitions of aquifers, highlighting porous, permeable materials capable of harbouring water. Many participants consider groundwater an important reserve, which contrasts with their perception of its limited abundance.

The groundwater drawings analysed are excessively schematic, lacking representation of recharge (rain, rivers, lakes) and discharge into rivers or lakes, as well as indications of water movement (arrows). These results are consistent with previous studies (Ben-Zvi-Assarf & Orion, 2005a; Reyero et al., 2007; Pan & Liu, 2018). Recognising groundwater as the main contributor to surface freshwater is crucial, as aquifer overexploitation is aggravated by population growth and climate change.

Some drawings reflect common classroom images (underground layers, karstic aquifers), sometimes with inaccuracies. This highlights how representations influence participants' understanding (Reyero et al., 2007).

Our results urge a review of teacher training, given teachers' central role in citizenship education. Understanding groundwater is essential for addressing challenges such as overexploitation, pollution and the responsible management of this resource. The existing awareness of its importance is a valuable starting point for improving teacher education.

Key hydrogeological issues should be more present in curricula to advance sustainability. This study provides data on teachers' conceptions of groundwater. Despite being preliminary and based on a limited sample, it offers valuable insights into a population that is key to sustainability education.

Acknowledgement

We thank all participants for their valuable contribution. This study was carried out within the Pensaciencias University–school collaboration network (No. 111) and supported by the research groups UCM 910607 and UCM 970826. It was funded by the Spanish Ministry of Science and Innovation (PGC2018-094955-A-I00; PID2022-138275NB-I00; PID2020-114358RB-I00) and by a project of the University of Valladolid (2024–2025, No. 124).

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Pre-Service Teachers' Behaviours Toward Environmental Problems

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Environmental issues pose significant challenges to ecosystems, biodiversity, and human health, making it crucial to examine behaviours that contribute to sustainability. Teachers play a key role in shaping students' environmental attitudes and actions. However, there is limited research on how pre-service teachers engage with environmental problems in their daily lives. This study aims to investigate pre-service teachers' behaviours toward environmental problems across different grades and departments. A survey research design was employed, and data were collected from 829 pre-service teachers from science, mathematics, social sciences, and primary education departments at a university in Turkey. The Environmental Problems Behaviour Scale, consisting of six sub-dimensions (perception, formation, guidance, skill transformation, adaptation to the situation, and creation), was used as the data collection tool. Descriptive and inferential statistical analyses, including t-tests, ANOVA, correlation, and multiple regression analyses, were conducted using SPSS 26. The findings revealed that pre-service teachers scored positively on the environmental behaviour scale. No significant differences were found in total scores based on gender, grade level, or department. However, significant positive correlations were observed among all sub-dimensions of the scale. Regression analysis showed that gender and grade level significantly predicted environmental behaviours, though the explained variance was low.

Keywords: Environmental education, pre-service teacher education, quantitative research

Introduction

Environmental issues have become one of the most pressing global challenges, impacting ecosystems, biodiversity, and human health. These issues threaten not only the environment but also future generations, making it even more critical to address them. Addressing these challenges requires a fundamental shift in individual behaviours toward sustainability. Teachers, as role models in society, play a significant role in shaping environmental attitudes and behaviours among students (Clayton et al., 2021).

From a behavioural perspective, environmental sustainability is often discussed in the literature as extending beyond environmental awareness or knowledge and involving how individuals respond to environmental issues in their daily lives. Previous studies have suggested that environmental knowledge and concern do not always directly translate into pro-environmental behaviour, and this relationship has been examined from different theoretical perspectives (Kollmuss & Agyeman, 2002; Kaiser & Wilson, 2004). In this respect, focusing on behaviours toward environmental problems may provide a descriptive understanding of how sustainability-related orientations are reflected in everyday practices.

However, there is limited research on how pre-service teachers from different disciplines personally engage with environmental issues and adopt behaviours toward environmental problems in their daily lives (Kollmuss & Agyeman, 2002; Monroe et al., 2019). Most existing studies focus primarily on environmental awareness, attitudes, or knowledge levels, while empirical evidence on behavioural dimensions—particularly multi-dimensional behavioural constructs—is still scarce. This gap is especially critical in teacher education, as pre-service

teachers are expected not only to possess environmental knowledge but also to model sustainable behaviours for their future students. Teacher education programs are therefore strategic contexts for fostering environmentally responsible behaviours. Understanding whether such behaviours differ according to gender, grade level, or disciplinary background can inform curriculum design and policy decisions aimed at strengthening environmental education in higher education. Examining these differences may also reveal whether current teacher education programs provide equitable and effective opportunities for developing sustainable behaviours across different subgroups.

Therefore, this study aims to examine the behaviours toward environmental problems of pre-service teachers from various grades and departments. Specifically, the study seeks to determine (a) the general level of pre-service teachers' behaviours toward environmental problems, (b) whether these behaviours differ according to gender, grade level, and department, and (c) the extent to which these demographic variables predict environmental behaviour. Understanding these behaviours can help develop targeted strategies and educational policies to enhance environmental responsibility among pre-service teachers, ultimately contributing to a more sustainable future.

Method

Research Design

Survey research design was used to achieve the purposes of this study. In survey research, researchers are generally interested in how and to what extent responses vary -their variability- how closely some responses are related to others, and how responses differ based on specific demographic variables or measures of social, political, or psychological factors (Fraenkel & Wallen, 2009). In line with this approach, the present study aimed to describe pre-service teachers' behaviours toward environmental problems and to examine how these behaviours vary according to selected demographic variables.

Participants

Convenience sampling, a technique that selects settings, groups, or people who are easily accessible and willing to participate in research, was used to determine the participants (Onwuegbuzie & Collins, 2007). Due to their logistical advantages in terms of time and money, pre-service instructors who were enrolled at the university where one of the researchers was based were included in this context. 829 pre-service teachers (581 females, 248 males) from science (161), mathematics (277), social sciences (195), and primary education (196) departments of a university in the Central Anatolia Region of Turkey participated in the study.

Data Collection Tool

Data for this study were collected using the Environmental Problems Behaviour Scale developed by Güven and Aydoğdu (2012). The scale consists of 40 items designed to measure individuals' behaviours toward environmental issues. Items are rated on a 3-point Likert-type scale.

The scale is structured around six factors: Perception (four items), formation (eight items), guidance (six items), skill transformation (10 items), adaptation to the situation (five items), and creation (seven items). The total score obtained from the scale was used as an overall indicator of behaviours toward environmental problems.

Data Analysis

The data were analysed using descriptive and inferential statistics. In order to examine the relationships between participants' behaviours and demographic variables, inferential statistics,

including independent samples t-tests and one-way ANOVA, were applied. A correlation analysis was also performed to assess the relationships between the sub-dimensions of the environmental behaviour scale. Lastly, multiple regression analysis was conducted to identify the factors that significantly predict pre-service teachers' behaviours toward environmental issues. In the multiple regression analysis, the total environmental problems behaviour score was treated as the dependent variable, while gender, grade level, and department were included as independent variables. All data analyses were performed using SPSS 26.

Findings

The results indicated that the mean total score of all pre-service teachers on the 40-item 3-point Likert scale was 90.64 (*SD* = 9.94), suggesting a generally positive level of behaviours toward environmental problems among the participants. Mean total scores for the six dimensions were as follows: Perception (*M*=9.05, *SD*=1.81), formation (*M*=17.60, *SD*=2.58), guidance (*M*=13.33, *SD*=2.03), skill transformation (M=23.73, *SD*=3.25), adaptation to the situation (*M*=11.47, *SD*=1.78) and creation (*M*=15.45, *SD*=2.24).

According to the independent samples t-test results, no significant difference was found in the total scores between male (*M*=88.59, *SD*=9.93) and female pre-service teachers (*M*=91.51, *SD*=9.83), indicating that gender did not lead to a meaningful difference in overall environmental behaviour scores at the group comparison level.

Table 1. Intercorrelations among the sub-dimensions of Environmental Problems Behaviour Scale.

	Perception	Formation	Guidance	Skill Transformation	Adaptation	Creation
Perception	-					
Formation	,510**	-				
Guidance	,356**	,382**	-			
Skill Transformation	,556**	,570**	,395**	-		
Adaptation	,455**	,436**	,304**	,490**	-	
Creation	,413**	,345**	,296**	,385**	,379**	-

One-way ANOVA results revealed no significant difference in total scores between pre-service teachers from the 1st (*M*=90.12), 2nd (*M*=90.07), 3rd (*M*=90.40), and 4th years (*M*=91.99) (*F*=1.755, *p*>.05). Moreover, one-way ANOVA results revealed no significant difference in total scores between pre-service teachers from the science (*M*=91.40), mathematics (*M*=89.86), social sciences (*M*=91.44), and primary education (*M*=90.33) departments (*F*=1.367, *p*>.05).

According to the correlation analysis results between the sub-dimensions of the environmental problems behaviour scale, all of the six sub-dimensions showed significant positive correlations with other five sub-dimensions (Table 1).

A multiple regression analysis was conducted to investigate how well gender, grade, and department predict pre-service teachers' behaviours toward environmental problems. In this analysis, the total environmental problems behaviour score was used as the dependent variable.

Regression analysis revealed that gender and class year significantly predicted total scores. The first model, including only gender, explained 1.8% of the variance in total scores ($R^2 = 0.018$, $F = 15.244$, $p < 0.001$). When grade level was added to the model, the explained variance increased to 2.5% ($R^2 = 0.025$, $F = 10.727$, $p < 0.001$). Gender was a significant predictor ($B = 2.92$, $p < 0.001$), with males scoring higher than females, while grade level also showed a significant effect ($B = 0.752$, $p = 0.014$). Department was excluded as it did not contribute significantly. Collinearity diagnostics indicated no issues (VIF values near 1).

Discussion And Suggestions

The average score of 90.64 indicates generally positive behaviours toward environmental issues among pre-service teachers, which aligns with previous studies showing that educators are more likely to engage in environmentally responsible actions (Kollmuss & Agyeman, 2002; Monroe et al., 2019). Although previous studies have reported gender-based differences in environmental behaviours (Kollmuss & Agyeman, 2002), the present study did not reveal a statistically significant difference between male and female pre-service teachers when group comparisons were conducted. This finding suggests that, at the descriptive level, environmental behaviours are distributed similarly across genders within the sample. One possible explanation for this could be the increasing efforts in educational institutions to promote environmental awareness equally among all students, regardless of gender.

The findings indicate no significant differences in the total scores of pre-service teachers from different departments (science, mathematics, social sciences, and primary education) on environmental issues. This suggests that there is no discernible difference in the environmental behaviours of pre-service teachers across disciplines. Studies in the field of environmental education often show that individuals from various academic backgrounds do not exhibit significant differences in their environmental awareness and behaviours (Monroe et al., 2019; Erdogan, 2013). The similarity in environmental attitudes across departments emphasizes the importance of interdisciplinary approaches in environmental education programs. Such programs can be effective in enhancing environmental consciousness among all teacher candidates, as fostering sensitivity to environmental issues should not be limited to a specific discipline.

The significant correlations between the sub-dimensions suggest that the formation and perception of environmental issues play a central role in influencing other behaviours such as skill transformation, guidance, and adaptation to the situation. This aligns with the works of Clayton et al. (2021) and Monroe et al. (2019), who highlighted that teachers' environmental perceptions significantly shape their ability to guide students toward sustainable behaviours. Moreover, the study shows that pre-service teachers' perceptions and the formation of environmental knowledge are strongly interconnected, which reinforces the idea that effective environmental education programs should focus on both cognitive and affective components (Erdogan, 2013).

The regression analysis revealed that gender and class year significantly predicted pre-service teachers' behaviours toward environmental problems. Interestingly, although no significant difference was found in the t-test, females scored higher than males, which contrasts with typical

findings (Kollmuss & Agyeman, 2002). The effect of grade suggests that more experienced students may be more engaged in environmental behaviours, potentially due to cumulative exposure to environmental education throughout their academic journey (Monroe et al., 2019). Interestingly, the department variable did not significantly contribute to the model, supporting the idea that environmental awareness is shaped more by broader educational experiences than by specific disciplines (Erdogan, 2013). This suggests that an interdisciplinary approach to environmental education might be more effective than focusing on particular fields of study.

Based on the findings of this study, several suggestions can be made for future research. Future studies may benefit from incorporating additional psychological, contextual, or institutional variables to better explain variations in environmental behaviour. Longitudinal research designs could be employed to examine how behaviours toward environmental problems develop over time throughout teacher education programs.

In addition, qualitative or mixed-methods approaches may provide deeper insights into how pre-service teachers interpret and enact environmental responsibility in their daily lives. Expanding the research to include multiple institutions or different cultural contexts could also enhance the generalizability of the findings.

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Studying Students' Reasoning About The Ozone Layer Depletion In The Context Of Argumentation

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The study focuses on the reasoning of 64 Greek upper secondary school students articulated in the context of an argumentation process about the ozone layer depletion, as part of a teaching-learning sequence regarding electromagnetic radiation, atmospheric-related issues and relevant policies. Participants were provided with a scenario specially designed for this purpose, which included evidence that could be used to support claims for or against specific actions, through the elaboration of particular reasoning. Results show that argumentation processes based on appropriately designed scenarios for the factors affecting ozone layer depletion could help students, to a certain degree, in developing reasoning to support claims such as in support of the ban of CFCs. We have identified specific elements of students' reasoning and organized them according to complexity, variability and flexibility. We also identified evidence of students' reasoning fragmentation.

Keywords: Ozone layer depletion, Reasoning, Argumentation

Introduction

Several studies in recent science education research literature explore students' understanding of the electromagnetic radiation-related atmospheric issues, including the relevant mechanisms of interactions between electromagnetic radiation and substances (e.g., Howard et al., 2013; Papadimitriou, 2004). Many of these studies highlight student difficulties related to understanding of such mechanisms involving relevant types of electromagnetic radiation, including those connected with ozone layer depletion (e.g., Çokadar, 2013; Kaya, 2009; Nyarko & Petcovic, 2021; Papadimitriou, 2004). The corresponding students' mental models seem to be particularly interesting, not only because it is found that, across educational levels, they include many misconceptions (Çokadar, 2013; Leighton & Bisanz, 2003), but also, because those concerning the ozone layer formation appear to be incoherent (Howard et al., 2013). We note specifically the existing evidence supporting the fragmentation of knowledge about the ozone layer itself and the ozone hole in particular (Leighton & Bisanz, 2003).

This fragmentation and inconsistency in students' mental models, as well as the lack of understanding and their misconceptions, are expected to have an impact on their reasoning, when issues related to the ozone layer depletion are discussed in the context of an argumentation process. This is the main purpose that framed the design of this study.

Theoretical framework

Students' understanding of the concepts of ozone, ozone layer and ozone depletion has attracted major interest from science education researchers. The relevant literature provides us with findings at various educational levels, from kindergarten to undergraduate students and pre-

service teachers (Leighton & Bisanz, 2003; Nyarko & Petcovic, 2021; Kaya, 2009). Although often students of different ages and educational levels are aware of some characteristics of the ozone layer, such as its nature, location and/or composition (Boyes et al., 1995; Boyes et al., 1999; Kaya, 2009; Nyarko & Petcovic, 2021; Pekel & Özay, 2005), various difficulties are identified, such as those related to the type of radiation involved in ozone layer depletion and function (Çokadar, 2013) or the understanding of the mechanism through which, electromagnetic radiation causes the ozone depletion and/or formation and the function of ozone broadly or the ozone layer in the earth's atmosphere (e.g., Nyarko & Petcovic, 2021; Çokadar, 2013; Howard et al., 2013). In addition, students appear to have difficulty in identifying ozone at ground level (e.g., Çokadar, 2013; Dove 1996;) and in the upper atmosphere (e.g., Çokadar, 2013). In line with this finding, problems are also identified at different ages and grades due to students' confusion with respect to the role of ozone in the stratosphere and troposphere (Bodzin et al., 2014; Howard et al., 2013; Kılınç et al., 2008). For instance, college students commonly believe that ozone formation in both the stratosphere and troposphere is attributed to one and the same single mechanism and that possible scepticism concerning the ozone layer is attributed to the role of ozone as a greenhouse gas (Howard et al., 2013). Students' confusion between ozone layer or ozone layer depletion and acid rain is also documented, since for instance, ozone depletion is being associated with acid rain, with students considering that the ozone layer protects Earth from acid rain (e.g. Nyarko & Petcovic, 2021).

Students' misunderstandings are also reported in relation to difficulties in identifying specific substances causing the ozone depletion, since confusion appears with the greenhouse gases (Kaya, 2009; Nyarko & Petcovic, 2021; Papadimitriou, 2004). Relevant studies that have been conducted across various ages and grades, provide us with findings indicating confusion between greenhouse effect (or global warming) and ozone layer depletion, based on the idea that ozone layer depletion and/or ozone holes are often believed to cause the greenhouse effect (or global warming) due to the increased solar energy, radiation or heat reaching the Earth through those ozone holes (e.g., Boyes & Stanisstreet, 1997; Dove, 1996; Kılınç et al., 2008; Österlind, 2005; Papadimitriou, 2004; Rye et al., 1997), or specifically due to increased ultraviolet radiation reaching the Earth's surface through them (e.g., Boyes & Stanisstreet, 1997; Çokadar, 2013; Dove, 1996; Kaya, 2009; Nyarko & Petcovic, 2021; Österlind, 2005; Papadimitriou, 2004; Rye et al., 1997). This idea has been found to be often expressed in a variety of students' mental models with coherent characteristics (e.g., Niebert & Gropengießer, 2014). On the other hand, knowledge about the ozone layer and ozone hole seems to be fragmented for younger students, in the elementary grades, due to the use of partial models and the absence of complete ones (Leighton & Bisanz, 2003), while incoherent models for the ozone layer formation are also found to be expressed by college students (Howard et al., 2013).

Research Questions

The lack of students' understanding of the concepts of ozone, ozone layer and ozone depletion, as well as, their relevant misconceptions, are expected to have an impact on students' reasoning when issues related to the ozone layer depletion are discussed. Thus, in this study, 11th grade upper high school students' reasoning is investigated during the development of arguments concerning the ozone layer depletion in the context of a teaching-learning sequence on climate change. Our main research questions were:

1. To what extent can students exploit data available in a given scenario concerning the ozone layer depletion in order to develop reasoning supporting a particular claim?

2. What are the basic elements of the reasoning that students develop within an argumentation context for the support of a particular claim concerning whether students are for or against the ban of CFCs?

Methodology

Participants were 64 Greek upper secondary students of the 11th grade of public schools who voluntarily participated in the study during the academic year 2023-2024, after informed consent had been obtained from their parents/legal guardians. In the context of a wider teaching-learning sequence about argumentation, electromagnetic radiation-related atmospheric issues and relevant policies, participants attended (among others) one 1-hour lesson about the ozone layer and its depletion, which was designed on the basis of the 5E teaching model.

Thus, after the initial stage of 'Engagement', students were attended relevant to ozone layer formation and depletion videos and simulations, during the 'Exploration' and 'Explanation' stages. In those stages, the ways, in which ozone layer is formed and those, in which it could be depleted, were explored with references to the effect of both the UV radiation and the catalytic action of some agents like CFCs, while the relevant explanations included mechanisms at the molecular level and further analyses with references to also other affecting factors like solar radiation intensity. In the 'Elaboration' stage, further discussion took place for the causes and the consequences of the whole phenomenon. Finally, in the 'Evaluation' stage of this model (about 15 min duration), students were provided with a specially designed scenario, in which two opposing views are developed in the context of relevant argumentation concerning the banning of CFCs in relation to the ozone layer depletion.

According to this scenario, the Montreal Protocol has banned the use of certain substances (commonly called CFCs) in order to protect the ozone layer. Several years after the ban, the ozone layer has indeed recovered to a significant extent, but depending on the year, its concentration exhibits significant fluctuations. Thus, scepticism developed about whether the annual fluctuations in the intensity of solar radiation or the action of CFCs is the most decisive factor in the ozone layer depletion, what would have happened if CFCs had not been banned, and whether all this effort was worth it.

Students were asked to study the scenario and to develop reasoning in the context of an argumentation process, supporting one of the claims provided, i.e. whether they are for or against the ban of CFCs. In brief, claims can be articulated as follows:

C1: I do not support banning the use of CFCs

C2: I support banning the use of CFCs (according to the Montreal protocol)

Students' responses were qualitatively analysed according to a three-step scheme as follows:

1. Students' responses were categorized according to the claim (C1, C2...) they supported.
2. For each one of the claims, students' reasoning was analysed by two independent raters (two of the authors) to isolate every distinct reasoning element (R1, R2….) that had a specific meaning.
3. Based on the isolated reasoning elements, students' reasoning was articulated accordingly, and a relevant categorization was followed.

Results

Students' reasoning was analysed by two independent raters (two of the authors) and every reasoning element having a particular meaning was recorded. Following this procedure, 14

reasoning elements (R1-12) were isolated, where 6 of these have a frequency from 15 to 45. Table 1 presents these reasoning elements.

Table 1. Students' reasoning elements (frequencies per category).

	Reasoning elements	N
R1	UV radiation breaks down the ozone molecule (forming oxygen molecule and oxygen atom)	8
R2	CFCs break down the ozone molecule (forming oxygen molecule and oxygen atom)	18
R3	CFCs under UV radiation break down the ozone molecule (forming oxygen molecule and oxygen atom)	12
R3a	UV radiation breaks down CFCs molecules forming chlorine atoms	15
R3b	A chlorine atom reacts with an ozone molecule forming oxygen molecule and ClO (and Cl is regenerated)	15
R4	Depletion of the ozone layer happens	45
R5	Ozone layer protect us from the UV radiation	1
R6	Penetration of UV radiation (through the atmosphere) happens	4
R7	Banning CFCs does not help	2
R8	The use of CFCs has been forbidden	27
R9	CFCs are not necessarily useful for us	1
R10	Total destruction of the ozone layer is avoided	33
R11	Comparing rates of destruction and regeneration	4
R12	The ozone layer is affected by variations in solar radiation	8

Based on the above reasoning elements (R1-12), students' responses were categorized as shown in Tables 2 and 3, with the exception of four students who did not respond. Specifically:

Table 2. Categories of students' reasoning leading to C1 (Number of students).

Category	Reasoning	N
1	Due to R1, then R7, thus C1	1
2	Due to R1, then R4 and R7, thus C1	1
3	Vague	3

Discussion And Conclusions

As shown in Tables 2 and 3, only few students (N=5) support C1 (*I do not support banning the use of CFCs*) based on the role of the UV radiation and ignoring the role of CFCs in the destruction of the ozone molecules (2 students), supporting the aspect that, substances causing the ozone layer depletion are not always recognizable by the students (Kaya, 2009; Nyarko & Petcovic, 2021). The vast majority of the students (N=55) support C2 (*I support banning the use of CFCs*). A number of them (N=15) focus on the catalytic destruction of the ozone molecules

(R3a, R3b), without taking into account the contribution of the UV radiation, advocating those suggest students' difficulties in problems understanding of the relevant mechanism (Nyarko & Petcovic, 2021; Çokadar, 2013). However, many of those supporting C2 (a total of 27 students, R8) take into account this contribution to the CFCs action, whereas some of them (15 students) can describe the mechanism of such an action, reporting the two relevant stages (R3a and R3b).

Table 3. Categories of students' reasoning leading to C2 (Number of students).

Category	Reasoning	N
1	Due to R1 and R2 then R4, thus, in order to R10, C2	2
2	Due to R1 and R2 then R4 and R6, thus, in order to R10, C2	1
3	Due to R2 then R4, thus C2	2
4	Due to R2 then R4 and R6, thus C2	2
5	Due to R2 then R4, and due to R9, thus C2	1
6	Due to R2 then R4, thus, in order to R10, C2	1
7	Due to R2 then R4, thus, in order to R10, and although R12, C2	1
8	Due to R2 then R4, thus, in order to R5, C2	1
9	Due to R2 then R4, and due to R8 then R10, thus C2	3
10	Due to R2 then R4, and due to R8 then R10, although R1, thus C2	1
11	Due to R2, and due to R8 then R10, thus C2	2
12	Due to R2 then R6, although R1, thus C2	1
13	Due to R3 then R4, although R12, thus C2	2
14	Due to R3 then R4, and due to R8 then R10, thus C2	6
15	Due to R3 then R4, and due to R8 then R10, and R11, thus C2	4
16	Due to R3a and R3b then R4, thus C2	4
17	Due to R3a and R3b then R4, thus, in order to R10, C2	2
18	Due to R3a and R3b then R4, and due to R8 then R10, thus C2	3
19	Due to R3a and R3b then R4, thus, in order to R10, and although R1, C2	1
20	Due to R3a and R3b then R4, although R12, thus C2	1
21	Due to R3a and R3b then R4, and due to R8 then R10, although R12, thus C2	2
22	Due to R3a and R3b then R4, although R12, and R8 did not stop R4, thus C2	2
23	Due to R8 then R10, thus C2	4
24	Vague	6

Among the reasoning elements used by the students, R4 (Depletion of the ozone layer happens) is the most frequent, whereas it is quite common for the students to recognize that the use of CFCs has been forbidden (R8), a fact that led to R10 (Total destruction of the ozone layer is avoided). However, it is quite interesting to see that some combinations of reasoning elements appear more frequently than others. The combination of reasoning elements R3 then R4, as part of a larger set of reasoning elements, appeared 12 times. The reasoning category "Due to R3a and R3b then R4, thus C2" appeared 4 times on its own, whereas the same combination of reasoning elements, as part of a larger set of elements, appeared 11 times. Also, the reasoning category "Due to R2 then R4, thus C2" appeared 2 times on its own, whereas the same combination of reasoning elements, as part of a larger set of elements, appeared 13 times. In addition, the reasoning category "Due to R8 then R10, thus C2" appeared 4 times on its own, whereas the same combination of reasoning elements, as part of a larger set of elements, appeared 21 times. Thus, it is apparent that, although there is broad variation in the reasoning patterns displayed by the students in response to the ozone layer depletion scenario, there are some combinations of reasoning elements that appear more frequent, facilitating the articulation of the whole students' arguments. Some of these combinations, especially in cases of students supporting C2, lead to the development of quite sophisticated reasoning involving adequately relevant elements, whereas in other cases, the whole reasoning appears to be quite simple.

However, more interesting is to focus on the variability existing in students' reasoning, where various reasoning emerge across students from the combination of different reasoning elements. Based on this variability it could be quite safe to a certain degree, to conclude that the classroom discourse has not reached coherent group knowledge and the group's understanding displays signs of fragmentation. In addition to the variability of the distinct reasoning elements that were identified, the same reasoning element or the same combination of reasoning elements can be activated, organized and function as part of a larger set of various interconnected reasoning elements or/and combinations of them leading to the articulation of multiple reasoning patterns, indicating the flexibility of these reasoning elements (e.g., Zarkadis & Papageorgiou, 2020). In addition to the variability and flexibility of students' reasoning elements, the reasoning elements, especially those supporting C2, appear to vary in their level of complexity, with reasoning element R3 [CFCs under UV radiation break down the ozone molecule (forming oxygen molecule and oxygen atom)] being more complex compared to R2 [CFCs break down the ozone molecule (forming oxygen molecule and oxygen atom)] and R1 [UV radiation breaks down the ozone molecule (forming oxygen molecule and oxygen atom)], reflecting a varying level of complexity of their reasoning which can fluctuate depending on how many and which reasoning elements are activated and the way they are organized as well.

In addition, it is important to notice, that many of the students' reasoning elements have common characteristics with the rationale, the elaborations and explanations developed during the lesson implemented in the context of the present study. As a result, it seems that argumentation processes based on appropriately designed teaching interventions, including scenarios for the factors affecting ozone layer depletion, could help students, to a significant degree, in developing reasoning in order to support their claims, such as those supporting the ban of CFCs.

Acknowledgement

This research was implemented under the ONISILOS MSCA COFUND fellowships program, which has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No 101034403

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Action Research On Climate Change Education In Lower Secondary School – Students' And Teachers' Experiences

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An action research study on the topic of climate change education was conducted in collaboration between science and social science education researchers and teachers at three lower secondary schools. After joint literature seminars, teachers planned and conducted teaching sequences on climate change, including an out-of-school visit to the collaborating university with a focus on increased local risk of flooding due to climate change. Interviews with students at the end of the study revealed that they appreciated the teaching sequence, tried to lead their personal lives in a climate-friendly way, but were not very engaged emotionally in climate change as an issue. Meeting notes and interviews with teachers show that science teachers prioritized teaching climate change as a physical phenomenon, but social science teachers expressed frustration with students' lack of emotional engagement and a perceived disconnect between students' knowledge of climate change and choices in their personal lives. Challenges in conducting action research in a situation with different objectives across the initiating municipality, and participating researchers, teachers, and students are discussed.

Keywords: Action research; Sustainability; Secondary Education

Introduction

Science education on the topic of climate change has primarily focused on students' development of knowledge of involved scientific phenomena, such as the greenhouse effect, and how they can contribute individually to mitigate climate change (Bofferding & Kloser, 2015). By limiting the focus to students' scientific knowledge and individual actions, there are many aspects of climate change that are not addressed in science teaching, including how society needs to adapt to climate change (Bofferding & Kloser, 2015; Kagawa & Selby, 2012), students' risk perception with regard to climate change (Aksit et al., 2018), and dealing with students' often negative emotions in relation to climate change (Ojala, 2016).

One important aspect of students' climate literacy is its influence on their willingness to act in climate-friendly ways (Garrecht et al., 2023). In this regard, climate-change education should aspire to develop of students' action competence, with the aim "to make present and future citizens capable of acting on a societal as well as a personal level" (Jensen & Schnack, 2006, p. 472).

Schools and teachers often lack tools for handling such complexities associated with climate change, and collaboration with educational researchers is an attractive option to develop relevant teaching approaches. In this light, the present study was initiated by the school administration of Karlstad, a medium-size municipality in Sweden, who contacted us as educational researchers regarding perceived anxiety in relation to climate change among secondary students in the municipality.

Aims And Research Questions

The overall aim of the study was to develop, conduct and analyse teaching sequences on the topic of climate change, with the ambition of supporting students' development of climate literacy (Garrecht et al., 2023). The study was guided by the following research questions:

- What didactical choices do teachers make and didactical challenges do they encounter in the context of teaching climate change?
- What are lower-secondary school students views on climate change, its impact on their everyday lives, and climate-change education?

Research Method And Design

A research project was formed with the purpose of developing, conducting, and analysing teaching sequences on the topic of climate change. The project team consisted of science and social science teachers from three lower-secondary schools in the municipality, and science education and social science education researchers.

The project team had a series of project meetings, that included literature seminars on the topic of climate psychology (Andersson et al., 2019), and sharing experiences of teaching climate change before and during the project. Our initial intention was to design the study as a participatory action research project (Eilks, 2018), where researchers and teachers collaborate in formulating research questions, designing teaching sequences, and analysing the enacted teaching. However, in reality, we came to take on more traditional roles, where researchers formulated research questions and analysed collected data, and teachers designed and carried out teaching sequences.

Teachers formed groups within the three schools and collaborated in planning the teaching of climate change (Nilsson, in press). In addition, students from the three schools (N = 150, age 14-15 years) visited the university for an out-of-school activity on climate change-related risk of flooding and local adaptations to such risk (Haglund et al., 2025).

Within the project, the following data have been collected:

- Meeting notes from the project meetings.
- Individual interviews and focus-group interviews with four (N = 4) of the participating social science teachers regarding their didactical choices and didactical challenges during planning and conducting climate change education (Nilsson, in press).
- Interviews with six (N = 6) of the participating students conducted after the teaching sequence on their experiences of the climate change education and their perception of climate change.
- Video data of pupils' engagement during the out-of-school activity (Haglund et al., 2025).

The present study focuses on the teachers' and students' experiences from the project. The student interviews have been analysed through thematic content analysis (Bryman, 2016).

Findings

Teachers' Views Of Climate Teaching

In the initial project meetings, some of the teachers, in particular science teachers, expressed that they did not recognise the description from the school administration that students have strong, negative emotions in relation to climate change. Instead, rather than being worried about increasing global temperatures, students were perceived to express concern about high petrol prices for their mopeds, in line with the focus of media and political debate in society during the time of data collection. In this light, these teachers prioritised teaching about the greenhouse effect as a physical phenomenon rather than addressing students' emotions with regard to climate change.

However, the interviews with the social science teachers revealed a more complex picture, identifying didactical challenges and dilemmas (Nilsson, in press). They expressed frustration that the students have a solid, factual knowledge of climate change, but do not manage to connect it to local risks or consequences for their everyday life. The students are concerned about getting high grades and cheap petrol, but not how to act in a climate-friendly way. Greta Thunberg, with her engagement in climate change, comes across as annoying to many students. With students' narrow focus on "will this be on the test?", the teachers struggled to bring global challenges into the classroom. In this regard, the teachers' personal values clashed with those of the students.

The teaching sequences that the social science teachers designed included watching the documentary film *2040* (Gameau, 2019), where students were introduced to examples of how current technologies and strategies might be used to mitigate climate change in the near future in order to stimulate a sense of hope. Students also compared the local risk of flooding and draught in locations close to rivers in Sweden and in Spain, and considered local adaptations and conflicts of interest in use of water (Nilsson, in press). In this way, the classroom teaching aligned with and built on the out-of-school visit to the university with a focus on flooding (Haglund et al., 2025).

Students' Views Of Climate Change And Climate Teaching

In the student interviews, the students expressed that they had enjoyed the climate change education, including the visit to the university. They appreciated the focus on concrete local risks of flooding during the visit to the university and getting to know how it has been addressed in urban planning:

> But it was also a bit, like… a wake up, or, what should I say… that we're in a risk zone in Karlstad, too… with flooding and things… /…/ to walk there and see places that you really know of and see that it can go bad. (Interview 1)

The students also appreciated the creative nature of the activities, such as how to respond to possible flooding scenarios, and the social setting during the out-of-school visit where they got to interact with students from other classes and representatives from the university student organisation Climate Students.

The students described that they try to act in a climate-friendly way in their families. In this regard, they showed an awareness of individual activities that are known to have a high impact on CO_2 emissions, such as flying on vacation, driving cars, and eating meat (Wynes & Nicholas, 2017), but also mentioned other activities that have less impact, such as reducing waste and recycling.

In line with the impression from the teachers, most of the students did not express strong, negative emotions with regard to climate change and how it is likely to affect their own future. However, after initial reassuring statements, more subtle worries were revealed. Three of the students said the following about their feelings in relation to climate change and its potential consequences in the future:

> Well, I sure don't have angst. /…/ I would say that if I have angst, it is angst about the animals. /…/ I mean, I care about the climate. And, of course, I think about the future, but… I am in the age where you focus on yourself, and mopeds… (laughter) (Interview 3)

> I don't get very anxious, but you can get a bit anxious about what will happen to future generations. Of course, if we don't stop… don't try to stop it now, there will be more and more problems for our children that will come. (Group interview, student 4)

> I don't want to live in a world that is horrible. And I don't want to give… to have my children live in a world that is horrible. You want to… but it is a bit tough to see that we will maybe live in a world where it is, like, crap to live. [laughter] (Interview 1)

In these interview excerpts, the students express concern about climate change, but do not see an immediate risk for themselves here and now, but rather for future generations or animals.

On the topic of how they may be affected by climate change, two of the students reflect on the consequences:

> And it is going to get a lot warmer, and we will maybe not have any snow in the winter, and things… so you will not be able to go skiing in Sweden, for example. (Interview 1)

> That we in Sweden maybe not will have access to as many different exotic fruits and stuff. There will not be enough to bring here, and that. It won't grow as well. (Group interview, student 5)

Not being able to ski or having a limited supply of exotic fruit come across as small and quite insignificant changes to their current way of living, which can be interpreted as naivety with regard to the likely impact on society of climate change.

Discussion

The study revealed large differences in perspectives on climate change among the teachers and researchers in the project team, the school administration that initiated the project, and the students that took part in the teaching. One reason for the different perspectives might be the rapid changes in the media focus, turning from sympathies with Greta Thunberg when the project was initiated to a concern about petrol prices when the teaching was planned. There may also be a difference in attitudes towards climate change depending on the place where the students lived and their schools were located, in a city or on the countryside.

However, there might be more fundamental reasons behind the differences between science teachers and social science teachers. The science teachers tended to prefer a focus on students' knowledge of climate change as a physical phenomenon, adhering to a traditional Vision I (Roberts, 2007) of scientific literacy. In contrast, the social science teachers had an ambition to address consequences for how the students lead their everyday lives and can engage in the community, which relates more closely to an alternative Vision II (Roberts, 2007) of scientific literacy.

The study highlights the need for a more integrated and interdisciplinary approach to teaching climate change in schools, one that bridges the differing perspectives among educators. While science teachers often prioritize a Vision I framework of scientific literacy, focusing on the physical phenomena that cause climate change, social science teachers emphasize the societal implications and students' roles as active citizens. These differing priorities reveal an opportunity for collaboration, where scientific understanding is combined with empowering students to develop the skills and confidence needed to make informed and responsible decisions in addressing climate change.

Acknowledgement

We would like to thank our colleagues within the project Bringing Climate Change to Schools (BriCCS), Carola Garrecht, Ute Harms, and Niklas Gericke, for valuable comments on the design and results of the study, and at the Center for Societal Risk Research (CSR) at Karlstad University, for the teaching resources and engagement in activities on the local risk of flooding. We are also grateful to the teachers and students that participated in the joint research effort and teaching activities. The project has been funded by the Swedish Research Council under grant number 2019-0360.

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Section: Transformative Learning In Environmental Education

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Fostering Environmental Science Competencies In The Anthropocene: Implementation Of The Four-Step AAAR Learning Cycle Using PISA 2025 Framework

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The Anthropocene highlights the growing impact of human activities on Earth's systems, creating complex environmental challenges that require more than scientific knowledge alone. This study investigated the effects of implementing the Four-Step AAAR (Awareness–Anticipation–Action–Reflection) learning cycle on upper secondary students' environmental science competencies, as defined in the PISA 2025 Science Framework. The study employed a mixed-methods, one-group pre-test–post-test design with 24 students in Northern Thailand, using community-based environmental issues, particularly plastic waste management, as the learning context. Quantitative data were collected through a PISA-aligned cognitive test and the Environmental Action Scale, while qualitative data were gathered from student reflections, classroom observations, and learning artifacts. The results showed a significant improvement in students' overall environmental science competencies, with large effect sizes across all competency dimensions. Qualitative findings indicated increased environmental awareness, stronger systems thinking, and the emergence of student agency through both everyday participation and leadership-oriented actions. The findings suggest that the AAAR learning cycle can effectively support competency-based and action-oriented environmental science education in the context of the Anthropocene.

Keywords: Citizen Science, Environmental Education, PISA

Principle And Rationale

From the late 19th century to the 21st century, human activities have profoundly disrupted Earth's ecological balance, ushering in an era termed the Anthropocene. The defining challenges of this epoch—climate change, biodiversity loss, and plastic pollution—threaten the sustainability of life on Earth. Among these issues, plastic pollution stands out due to its ubiquity, persistence, and severe ecological consequences. Poor waste management and excessive reliance on single-use plastics exacerbate global environmental degradation, making the problem a pressing educational priority.

The Anthropocene underscores the power of human activities to reshape Earth's systems—from the fossil-fuel combustion of the industrial revolution to the global proliferation of plastic waste. While plastic use has enabled various economic conveniences, it has also generated persistent waste that infiltrates landfills, rivers, and oceans. In Northern Thailand, such environmental degradation converges with the cross-border haze crisis. For decades, Chiang Mai and Chiang Rai have experienced PM2.5 pollution that exceeds international standards. This air pollution is further exacerbated by cultural and economic practices, including large-scale cremations, waste burning, and agricultural burning—collectively posing serious threats to public health and elevating rates of lung cancer and respiratory diseases (Masters et al., 2021; OECD, 2023).

The Anthropocene also manifests through extreme weather events in Thailand's northern regions. The 2024 flood in Chiang Rai, for example, caused widespread damage to infrastructure, agriculture, and local communities, amplifying economic burdens and health risks. The flood also

generated large volumes of waste—including household garbage, construction debris, and plastic materials—that overwhelmed existing waste management systems. Meanwhile, repeated open-air cremations in some areas, traditionally practiced as part of funerary rites, release additional pollutants into an already compromised atmosphere. Consequently, Northern Thailand has emerged as a vivid case study of the Anthropocene's complexity, illustrating how localized cultural practices and socio-economic factors intersect with global environmental crises.

Educational efforts to address these challenges increasingly focus on equipping students with the competencies to understand, evaluate, and mitigate environmental problems. UNESCO's vision of Education for Sustainable Development (ESD) and the OECD's Programme for International Student Assessment (PISA) 2025 Science Framework converge on this point. Both emphasize action-oriented learning that integrates scientific knowledge with community engagement.

Purposes And Research Questions Of The Study

The purposes of this study were (1) To investigate the effects of implementing the four-step AAAR (Awareness–Anticipation–Action–Reflection) learning cycle on upper secondary students' environmental science competencies, as defined in the PISA 2025 Science Framework. (2) To examine changes in students' environmental science competencies before and after participation in the AAAR-based learning intervention.

Accordingly, this study was guided by the following research question, which asks how the implementation of the four-step AAAR learning cycle influences upper secondary students' environmental science competencies based on the PISA 2025 Science Framework.

Conceptual Definitions

Environmental Science Competencies (ESC)

According to the PISA 2025 Science Framework, three Environmental Science Competencies (ESC) guide the educational preparation of 15-year-olds to face complex socio-ecological challenges (OECD, 2023):

(1) Explaining the impact of human interactions with Earth's systems. This refers to the understanding of the relationships among physical systems, living organisms, and Earth systems. It includes recognizing both the positive and negative impacts of human activities over time, and the ability to comprehensively analyse social, cultural, and economic factors that affect the environment.

(2) Making informed decisions and taking action based on diverse evidence. This refers to the capacity to access and critically evaluate evidence from various sources, and to design environmental solutions using creativity and systems thinking. It also involves civic engagement, goal-setting with people across generations, and working towards environmental restoration and sustainability from the local to the global level.

(3) Demonstrating hope and respect for diverse perspectives. This refers to acting ethically and demonstrating care for living beings, recognizing and addressing social injustices, showing determination in the face of ecological crises, and respecting diverse viewpoints. It includes seeking solutions to restore the environment in inclusive and hopeful ways

Four-Step AAAR Learning Cycle

The Four-Step AAAR Learning Cycle is an iterative learning cycle consisting of Awareness, Anticipation, Action, and Reflection, designed to continuously develop learners' thinking

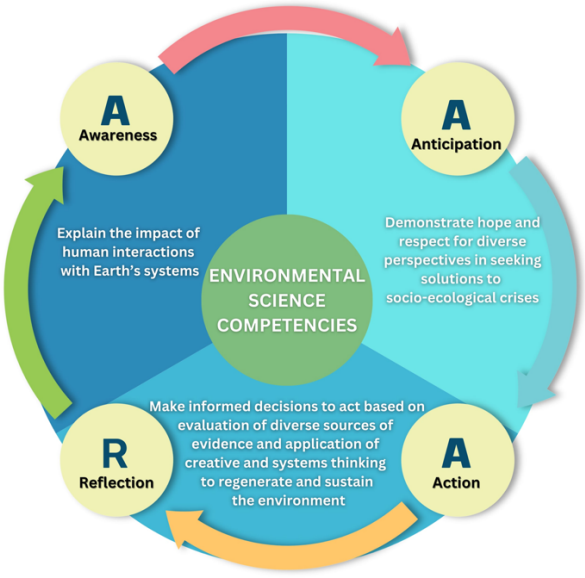
through intentional and responsible engagement, leading to positive change for self, society, and the environment.

The AAAR cycle is adapted from the OECD Learning Compass 2030 AAR cycle (Anticipation–Action–Reflection) by explicitly adding Awareness as a preparatory step.(Mangkhang, C., 2021)

Conceptual Framework

Based on preliminary findings from surveys, interviews, and student reflections, the study revealed that while students demonstrated awareness of environmental issues, particularly plastic waste, their understanding of systemic environmental impacts and confidence in taking action remained limited. These findings indicated a gap between environmental awareness and meaningful engagement in environmental problem-solving. In response, this study focused on community-based environmental issues, specifically waste management and plastic pollution, as authentic learning contexts. To address this gap, the Four-Step AAAR (Awareness–Anticipation–Action–Reflection) learning cycle was employed as a pedagogical framework to guide students through recognizing local environmental problems, anticipating future consequences, engaging in responsible actions, and reflecting on their learning experiences. Through this iterative learning process, students were expected to develop environmental science competencies aligned with the PISA 2025 Science Framework, including systems thinking, informed decision-making, and student agency.

Figure 1. Research conceptual framework.



Literature Review

The Anthropocene And Environmental Challenges In Education

The Anthropocene highlights the profound influence of human activities on Earth's systems, resulting in complex environmental challenges such as climate change, biodiversity loss, and pervasive plastic pollution (OECD, 2019; White et al., 2024). These challenges are not only global but also deeply embedded in local socio-cultural contexts. In many regions, including Northern Thailand, environmental problems such as plastic waste accumulation, air pollution, and extreme weather events increasingly affect community well-being. Addressing such complexity requires educational approaches that move beyond content knowledge toward

empowering learners to understand and engage with real-world environmental issues (UNESCO-UNEP, 1978; OECD, 2023).

Environmental Science Competencies And The PISA 2025 Framework

In response to the demands of the Anthropocene, the PISA 2025 Science Framework emphasizes the development of Environmental Science Competencies (ESC) that enable students to explain human–environment interactions, make informed decisions based on evidence, and demonstrate respect for diverse perspectives (OECD, 2023). Central to these competencies is the notion of student agency, which involves learners' capacity to participate meaningfully in addressing environmental challenges. Research suggests that while students may demonstrate awareness of environmental problems, they often lack opportunities to develop the competencies and confidence required for informed action (Masters et al., 2021). Consequently, educational frameworks increasingly highlight competency-based and action-oriented learning as essential for environmental education in the Anthropocene.

Action-Oriented Learning For Sustainability

Action-oriented and competency-based learning approaches have been widely advocated within Education for Sustainable Development (ESD) as a means to bridge the gap between awareness and action (UNESCO-UNEP, 1978). Such approaches emphasize authentic learning contexts, community engagement, and reflective practices that allow students to connect scientific knowledge with everyday environmental issues. Studies have shown that context-based and community-oriented learning can support students' systems thinking and ethical awareness, particularly when learning activities are grounded in local environmental challenges (Mangkhang et al., 2021; Masters et al., 2021). However, there remains a need for structured pedagogical models that systematically guide learners from recognizing environmental problems to taking responsible action.

The Four-Step AAAR Learning Cycle

The Four-Step AAAR (Awareness–Anticipation–Action–Reflection) learning cycle builds upon the OECD Learning Compass 2030, which emphasizes anticipation, action, and reflection as key processes for developing learner agency (OECD, 2019). By explicitly incorporating awareness as a preparatory stage, the AAAR cycle provides a structured framework for engaging learners with environmental issues in a holistic manner. The cycle guides students to recognize environmental problems, anticipate future consequences, take informed and responsible action, and reflect on their experiences to inform subsequent learning. This iterative process aligns closely with the goals of environmental science competencies and supports the development of student agency in addressing complex environmental challenges (OECD, 2023).

Taken together, existing literature highlights the need for pedagogical approaches that integrate local environmental contexts, competency-based learning, and action-oriented processes. However, limited empirical research has examined how structured learning cycles such as the AAAR model can be used to foster environmental science competencies within the framework of PISA 2025, particularly in culturally and contextually specific settings. This study seeks to address this gap by implementing the AAAR learning cycle in the context of community-based environmental issues.

Research Design, Scope, And Methods

Variables

- **Independent Variable:** The implementation of the four-step AAAR learning cycle integrated into science learning activities.

- **Dependent Variables:** Students' environmental science competencies as defined by the PISA 2025 Science Framework

Participants

The participants were 24 upper secondary students aged 15–17 years from a public secondary school in Northern Thailand. The school is situated in an area facing environmental challenges such as plastic waste, air pollution, and periodic flooding. Participation was voluntary, and informed consent was obtained from both students and their guardians prior to data collection.

Instruments

Types Of Research Instruments

To address the research objectives, both quantitative and qualitative research instruments were employed.

(1) Cognitive Test

A PISA-aligned cognitive test was developed to assess students' environmental science competencies, with a focus on problem-solving related to plastic pollution and waste management. The test measured students' ability to apply scientific knowledge, interpret data, and propose evidence-based solutions to environmental problems. The instrument was administered before and after the AAAR-based learning intervention.

(2) Environmental Action Scale (EAS)

The Environmental Action Scale, adapted from Alisat and Riemer (2015), was used to assess students' self-reported pro-environmental behaviours and intentions. The scale consisted of Likert-type items addressing daily environmental practices, participation in environmental activities, and willingness to engage in community-based environmental actions.

(3) Qualitative Instruments

Qualitative data were collected to capture students' learning experiences, engagement, and emerging agency throughout the AAAR-based learning activities. Three qualitative instruments were employed: student reflection logs, classroom observations, and student worksheets, all of which were aligned with the four phases of the AAAR learning cycle.

Steps To Create And Validate Research Instruments

This study followed a systematic process to develop and validate research instruments aligned with the research objectives, the Environmental Science Competencies in the PISA 2025 Science Framework, and the Four-Step AAAR learning cycle.

First, the Environmental Science Competencies defined in the PISA 2025 framework were analysed and translated into measurable learning outcomes, which guided the development of all research instruments and learning activities.

Second, both quantitative and qualitative instruments were developed, including a cognitive test of environmental science competencies, an adapted Environmental Action Scale (EAS), and qualitative tools such as student reflection logs, worksheets, and classroom observation protocols. Four AAAR-based lesson plans were also designed as the instructional framework and sources of qualitative evidence.

Third, all instruments and lesson plans were reviewed by experts in science education and curriculum studies to evaluate content validity, clarity, and alignment with the research objectives. Expert feedback was used to revise the instruments.

Finally, the revised instruments were piloted with a small group of students outside the main study, and minor adjustments were made before final implementation for pretest, posttest, and ongoing qualitative data collection.

Data Collection And Analysis

Data Collection

Data were collected throughout the implementation of the four AAAR-based lesson plans using both quantitative and qualitative approaches. Quantitative data were obtained through a cognitive test aligned with the PISA 2025 Science Framework and the Environmental Action Scale (EAS). The cognitive test and EAS were administered to students before and after participation in the AAAR-based learning activities to examine changes in environmental science competencies and pro-environmental behaviours.

Qualitative data were collected concurrently during the instructional intervention. Sources of qualitative data included student reflection logs, classroom observations, and student worksheets produced during the Awareness, Anticipation, Action, and Reflection phases of each lesson plan. These data captured students' learning experiences, engagement, reasoning processes, and emerging agency related to community-based environmental issues, particularly plastic waste management and pollution.

Data Analysis

Quantitative data were analysed using descriptive and inferential statistics. Descriptive statistics, including means and standard deviations, were calculated to summarize students' pretest and posttest scores. Due to the small sample size and non-normal distribution of the data, the Wilcoxon Signed-Rank Test was used to examine differences between pretest and posttest scores. Effect sizes were calculated to determine the magnitude of learning gains following the AAAR-based learning intervention.

Qualitative data were analysed using thematic analysis. Student reflection logs, observation notes, and learning artifacts were systematically reviewed and coded to identify recurring patterns and themes. The analysis focused on themes related to environmental awareness, systems thinking, decision-making, values and responsibility, and student agency. The identified themes were then interpreted in relation to the phases of the AAAR learning cycle and the Environmental Science Competencies defined in the PISA 2025 framework.

To enhance the credibility of the qualitative findings, data triangulation was employed by comparing evidence across multiple data sources, including reflections, observations, and student-produced artifacts.

Research Advantages

This study demonstrates how the Four-Step AAAR learning cycle can be effectively applied to foster environmental science competencies aligned with the PISA 2025 framework. By grounding learning activities in real-world, community-based environmental issues such as plastic waste, the study enhances the relevance of science learning and supports the development of student agency. The findings also provide practical AAAR-based lesson plans that can be adapted by educators to promote action-oriented and competency-based environmental education.

Results

Quantitative Results

Table 1. Descriptive Statistics and Wilcoxon Signed-Rank Test of Environmental Science Competencies before and after

N	Mean of Pre-test	Mean of Post-test	Mean difference	Statistic	P-value	Effect Size	Interpretation
24	78.9	90.8	11.00	300	<.001*	1.00	Large Effect

Note *P-value <.05 interpreted as significant. Effect Size interpreted according to Cohen (1988): .00-.09 Negligible, .10-.29 Small, .30-.49 Medium, ≥ .50 Large

Table 2. Descriptive Statistics and Wilcoxon Signed-Rank Test of Environmental Science Competencies Before and After in Each Dimension

Components of Environmental Science Competencies	N	Mean of Pre-test	Mean of Post-test	Mean difference	Statistic	P-value	Effect Size	Interpretation
1. Explain the impact of human interactions with Earth's systems	24	24.2	30.5	6.00	300	<.001*	1.00	Large Effect
2. Make informed decisions to act based on evaluation of diverse sources of evidence and application of creative and systems thinking to regenerate and sustain the environment	24	48.0	52.8	5.00	246[a]	<.001*	1.00	Large Effect
3. Demonstrate respect for diverse perspectives, and hope, in seeking solutions to socio-ecological crises	24	8.50	10.21	2.00	186[a]	<.001*	0.958	Large Effect
4. Environmental Action Scale								
4.1 Participatory Actions	24	11.7	18.1	7.00	211[a]	0.007	0.664	Large Effect
4.2 Leadership Actions	24	1.13	4.04	4.50	88.5[a]	0.026	0.686	Large Effect

Note P-values <.05 interpreted as significant. Effect Size interpreted according to Cohen (1988): .00-.09 Negligible, .10-.29 Small, .30-.49 Medium, ≥ .50 Large

Quantitative analysis revealed a significant improvement in students' overall environmental science competencies following participation in the AAAR-based learning activities. Post-test scores were significantly higher than pre-test scores, as indicated by the Wilcoxon Signed-Rank Test ($p < .001$). The results demonstrated a large effect size, suggesting that the learning gains were not only statistically significant but also educationally meaningful.

Further analysis by competency dimension showed consistent improvement across all components of environmental science competencies as defined in the PISA 2025 Science Framework. Students demonstrated increased ability to explain the impact of human interactions with Earth's systems, make informed decisions based on evidence and systems thinking, and demonstrate respect for diverse perspectives in addressing socio-environmental issues. In addition, scores on the Environmental Action Scale (EAS) showed statistically significant improvement, indicating positive changes in students' reported pro-environmental behaviours and intentions. Overall, the quantitative findings indicate that the AAAR-based learning intervention supported students' competency development across multiple dimensions.

Qualitative Results

Emerging Themes From Qualitative Data

Qualitative analysis of student reflection logs, classroom observations, and learning artifacts revealed several recurring themes that supported the quantitative findings.

The first theme was environmental awareness and real-life connection. Students demonstrated increased awareness of local environmental issues, such as plastic waste, flooding, and air pollution, and were able to connect these issues to their daily lives and community contexts.

The second theme was systems thinking and future-oriented reasoning. Students increasingly described environmental problems in terms of cause–effect relationships and long-term consequences, including links between waste accumulation, greenhouse gas emissions, and climate-related impacts.

The third theme was values, responsibility, and participation. Many students expressed a growing sense of responsibility toward environmental protection and reported changes in daily behaviours, such as waste separation and reduced plastic use. Some students also shared their learning with peers and family members.

Evidence Of Student Agency

Qualitative evidence further highlighted the development of student agency during the AAAR learning cycles. Some students, particularly those involved in student councils, demonstrated leadership by initiating environmental projects, such as organizing waste separation points and designing community-based campaigns to reduce plastic use. Other students expressed agency through personal behaviour change and future-oriented commitments, as reflected in reflective journals and letters to their future selves. These findings indicate that the AAAR learning cycle supported students in moving beyond awareness toward participation and leadership in environmental action.

Discussion

The findings indicate that the AAAR learning cycle effectively supported the development of environmental science competencies aligned with the PISA 2025 Science Framework. The significant overall improvement suggests that the integration of awareness, future-oriented thinking, action, and reflection created meaningful learning experiences that extended beyond knowledge acquisition toward competency development (OECD, 2023). By engaging students with community-based environmental issues, particularly plastic waste management, the learning process enabled students to connect scientific concepts with real-world contexts, which has been widely recognized as a key condition for effective environmental science education (Stevenson et al., 2013; Wals, 2012).

One important explanation for the observed gains lies in the structure of the AAAR learning cycle itself. The Awareness phase helped students recognize environmental problems as personally and socially relevant, increasing their motivation to engage with scientific content. The Anticipation phase encouraged systems thinking and future-oriented reasoning, allowing students to explore cause–effect relationships and long-term consequences of human–environment interactions, which are central to environmental science competencies in PISA 2025 (OECD, 2023). These phases prepared students to move beyond fragmented understanding toward a more holistic view of environmental challenges characteristic of the Anthropocene. However, differences were observed in students' environmental action and leadership outcomes. Student council members tended to demonstrate stronger gains in leadership-oriented actions compared to their peers. This pattern may be explained by their prior experience in decision-making, collective responsibility, and participation in school governance, which likely enhanced their perceived self-efficacy and ability to translate learning into visible leadership actions (Bandura, 2001). Similar findings have been reported by Alisat and Riemer (2015), who noted that students with previous leadership opportunities are more likely to engage in collective environmental action and advocacy. Most students in the classroom showed growth primarily in participatory and everyday environmental actions, such as changing personal behaviours, engaging in group activities, and sharing environmental knowledge with peers and family members. These outcomes reflect forms of "everyday agency," which are often more accessible and immediately achievable for learners than formal leadership roles (Kollmuss & Agyeman, 2002). Such findings align with research suggesting that environmental engagement typically begins at the individual level before developing into broader social or political action (Chawla & Cushing, 2007). A small number of students demonstrated limited improvement or slight decreases in leadership-related scores. Rather than indicating a failure of the learning intervention, this result highlights that student agency develops at different paces and is influenced by multiple internal and external factors, including motivation, personal values, social norms, and perceived opportunities for action (Ajzen, 1991). Environmental competence should therefore be understood as a dynamic and contextual process rather than a uniform outcome for all learners. Previous studies in environmental education similarly report that increased awareness does not always lead immediately to observable action or leadership, particularly within short intervention periods (Chawla & Cushing, 2007).

Importantly, the qualitative findings suggest that even students who did not show strong quantitative gains in leadership began to recognize their own potential roles in environmental action. Reflective journals and learning artifacts indicated emerging awareness of personal responsibility and future commitments, suggesting that agency may be developing in less visible but still meaningful ways. This supports the view that education for sustainability is inherently a long-term process, shaped by both individual trajectories and socio-cultural contexts (UNESCO, 2020; Wals, 2012).

Overall, these findings highlight that while the AAAR learning cycle can foster environmental action and student agency, differentiated support and extended time may be necessary to engage all learners meaningfully, particularly those who are less inclined toward leadership roles. Providing diverse pathways for participation—ranging from personal behaviour change to collective and leadership-oriented action—may help ensure that all students can develop environmental science competencies in ways that align with their capacities and contexts (White et al., 2024). In this sense, the AAAR learning cycle offers a flexible and promising framework for competency-based, action-oriented environmental science education in the Anthropocene.

Conclusion

This study demonstrates that the Four-Step AAAR learning cycle can effectively support the development of environmental science competencies aligned with the PISA 2025 framework. Through the integration of community-based environmental issues into science learning, students showed improved understanding of human environment interactions, stronger evidence-based decision-making, and emerging forms of student agency. While not all students demonstrated leadership-oriented actions, the findings highlight that environmental agency can develop through diverse pathways, including everyday participation and personal **behaviour** change. The study contributes empirical evidence on how action-oriented and competency based learning can be implemented in upper secondary science classrooms using a structured learning cycle. Future research may extend this approach across longer timeframes or varied contexts to further explore how different forms of agency can be fostered in environmental science education.

Implications

The findings suggest that the AAAR learning cycle can serve as a flexible framework for designing competency-based environmental science learning across various contexts, not limited to waste-related issues. Teachers may adapt this approach to address different environmental challenges relevant to their local settings. In addition, future research may benefit from longer-term implementations to examine how environmental competencies and student agency develop over time.

Acknowledgement

This research was completed with the support of many individuals and institutions. The author sincerely thanks the participating students, the thesis advisor for valuable guidance and feedback, and the school for permission and support during data collection. The author also gratefully acknowledges my parents and friends for their encouragement and support throughout the research.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Developing Environmental Competencies And Identities Through A Trans-Contextualization Learning Process Using Socio-Scientific Issues

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Rapid socio-environmental change calls for science education that equips students to reason and act on complex sustainability challenges. This study examined the effectiveness of a Trans-Contextualization Learning Process Using Socio-Scientific Issues (TCUSSI) in strengthening Grade 8 students' environmental competencies (EC) and environmental identities (EI) through two SSI contexts—fossil fuels and food waste—sequenced across micro (personal), meso (local), and macro (global) levels. Grounded in the PISA 2025 Science Framework, the intervention engaged learners in evidence-based reasoning, systems thinking, and reflection on civic responsibility. Participants were 32 Grade 8 students in Lampang Province, Thailand. A mixed-methods design employed an Environmental Competencies Test (ECT) adapted from PISA-style tasks and an Environmental Identities Questionnaire (EIQ) based on Clayton (2003), complemented by open-ended responses and reflective journals. Findings indicated significant gains in all EC components and in four of five EI components, with large effect sizes, and a moderate post-intervention correlation between EC and EI. Qualitative evidence corroborated increased awareness, local–global sustainability linkages, and emerging youth agency, while highlighting challenges in quantitative reasoning and behaviour–intention alignment. Overall, TCUSSI demonstrates strong potential as a contextually grounded socio-scientific pedagogy for lower secondary sustainability education.

Keywords: Trans-Contextualization Learning Process Using Socio-Scientific Issues, Environmental Competencies, Environmental Identities

Introduction

Rapid societal changes in science, technology, economics, and the environment have produced interconnected impacts at both local and global levels. In recent decades, fluctuating economies, aging populations, disease outbreaks, borderless information exchange, and escalating climate crises underscore the urgent need for awareness and preparedness (Holbrook et al., 2022). In this context, education is critical for equipping young people to respond to current and future challenges. Contemporary educational goals increasingly emphasize holistic well-being by integrating health, civic engagement, social connection, and environmental stewardship (OECD, 2023), and the OECD (2019) highlights that such outcomes support the development of active global citizens who can contribute to sustainable development and social responsibility.

Science education, in particular, must prepare learners to engage with complex socio-environmental problems by strengthening their capacity to navigate multifaceted issues (Sadler & Zeidler, 2009). Many contemporary challenges—such as nuclear risks, genetic dilemmas, global warming, and resource depletion—are inherently socio-scientific because they require scientific understanding alongside ethical and social judgment (Chowdhury, 2022). As a result, educators increasingly adopt socio-scientific issues (SSI)—controversial topics that connect social contexts with scientific inquiry—to foster evidence-based argumentation and responsible decision-making (Presley et al., 2013). A key pedagogical support for SSI is context-based learning, which anchors scientific ideas in familiar situations and gradually expands learning

toward broader contexts (Chowdhury, 2022; Holbrook et al., 2022). This staged movement across micro (personal), meso (local), and macro (global) contexts is also consistent with the OECD's PISA 2025 Science Framework (OECD, 2023).

In addition, responding to environmental crises such as climate change requires attention not only to what students know and can do, but also to how they perceive their relationship with nature. EI influences whether learners see themselves as part of interconnected ecosystems and engage in ecological problem-solving (Clayton, 2003). Therefore, integrating SSI with identity-oriented and contextualized learning may support the development of both EC and EI that underpin environmentally responsible citizenship.

In response to these needs, this study examines the effectiveness of TCUSSI for lower secondary students. The study investigates whether TCUSSI strengthens Grade 8 students' EC and EI and examines the relationship between EC and EI following participation in the TCUSSI intervention among 32 Grade 8 students in a district secondary school in Lampang Province, Thailand. Accordingly, the study addresses two research questions:

(1) To what extent does the TCUSSI intervention enhance Grade 8 students' EC and EI?

(2) What is the relationship between EC and EI among students after participating in the TCUSSI intervention?

Theoretical Background

SSI are open-ended problems in which scientific knowledge intersects with ethical, social, and political considerations. SSI-based learning is therefore a key approach for developing evidence-based reasoning and responsible decision-making in science education (Sadler & Zeidler, 2009). A persistent limitation, however, is that SSI learning can remain confined to classroom argumentation without systematically connecting students' reasoning to lived experiences or to wider societal and global realities. This study therefore adopts TCUSSI, which structures learning across micro (personal), meso (local/community), and macro (global) contexts so that learners revisit the same issue with increasing systemic complexity and civic relevance (Holbrook et al., 2022). This sequencing follows the logic of context-based learning—starting from familiar situations and extending understanding across broader contexts—while providing a coherent trajectory for sustained meaning-making (Chowdhury, 2022). In this study, TCUSSI is enacted through the unit Our World using fossil fuels and food waste as SSI contexts and implemented through four stages: contextualization, de-contextualization, re-contextualization, and trans-contextualization (Holbrook et al., 2022).

Within TCUSSI, the study targets two complementary outcomes—EC and EI. EC represent students' capacity to understand and respond to socio-ecological challenges in the Anthropocene (Ketsing, 2023). Consistent with the PISA 2025 Science Framework, EC are defined as the ability to explain human interactions with Earth's systems, make informed decisions using diverse evidence and systems thinking, and demonstrate respect for diverse perspectives and hope when addressing socio-ecological crises (OECD, 2023). Developing EC requires learners to interpret information and justify decisions through evidence-based and systems-oriented reasoning, which aligns with competence development in SSI-based learning (Presley et al., 2013).

EI complement competence-based outcomes by explaining how learners perceive their relationship with nature and their role within socio-ecological systems. EI are defined as how individuals perceive and define their relationship with nature, encompassing the importance of personal interactions with nature, self-identification within ecosystems, commitment to sustainability, positive emotions toward nature, and autobiographical memories of engaging with

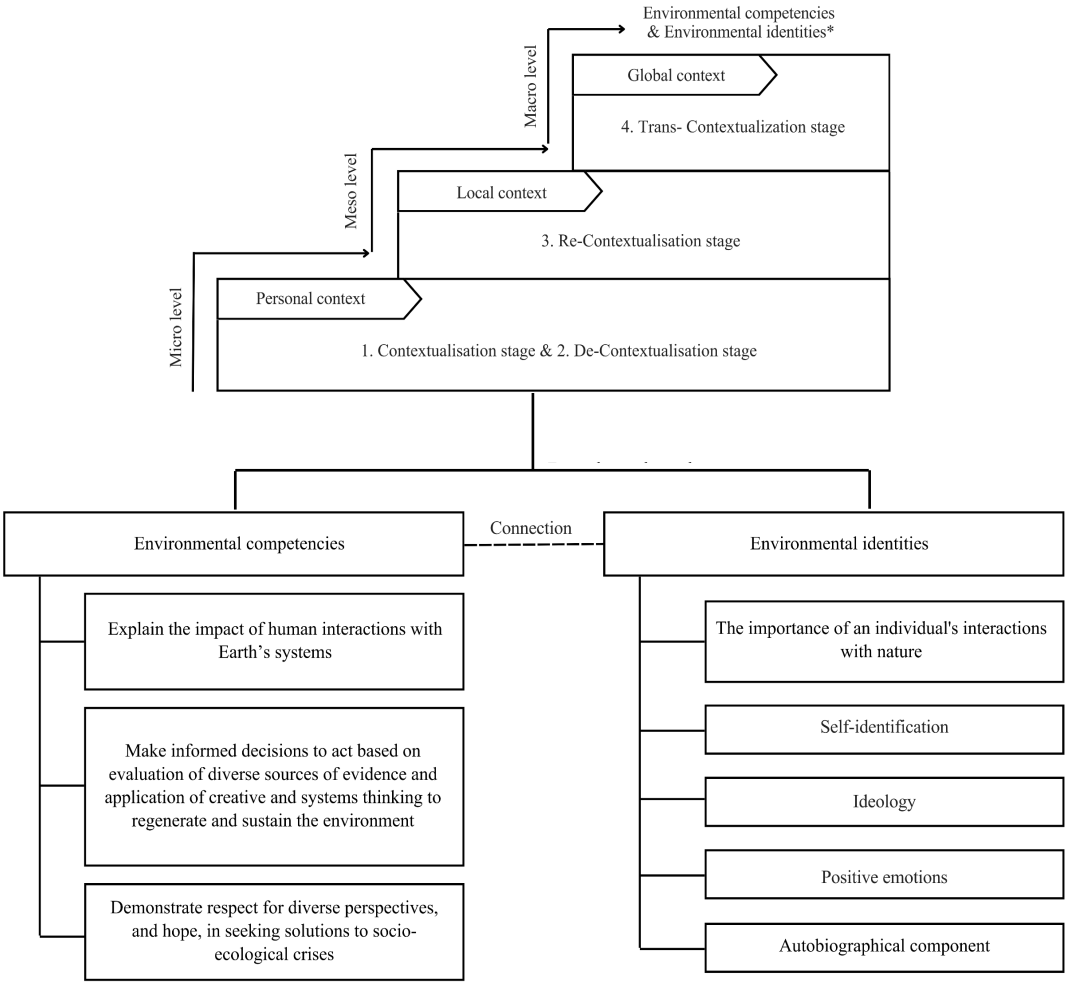
nature (Clayton, 2003). Empirical work suggests that stronger EI are associated with pro-environmental attitudes and behavioural change, particularly when learning invites reflection and connects environmental issues to students' sense of self (Blatt, 2013).

Prior studies indicate that SSI and contextualized learning can deepen understanding, improve argumentation, and foster ethical awareness (Tal & Kedmi, 2006), while staged contextual movement can support learners' agency in addressing both everyday and global dilemmas (Sadler et al., 2016). Trans-contextual learning further extends this potential by linking local concerns to global sustainability challenges and strengthening orientations aligned with active informed citizenry (Chowdhury et al., 2020; OECD, 2019). Yet, evidence remains limited on whether trans-contextual SSI learning can simultaneously strengthen EC and EI and bring these outcomes into closer alignment. This study therefore examines TCUSSI as a coherent theoretical approach for investigating growth in EC and EI among lower secondary students and for exploring whether the relationship between EC and EI becomes stronger following the intervention.

Conceptual Framework

The conceptual framework of this study, outlining the expected linkage between TCUSSI and the concurrent development of EC and EI, is presented in Figure 1.

Figure 1. Research conceptual framework.



This study conceptualizes TCUSSI as a mechanism that integrates SSI-based learning across micro–meso–macro contexts to support the concurrent development of EC and EI. As students progress from personally meaningful situations to local and global sustainability challenges, they are expected to strengthen their ability to explain human–Earth system interactions and make evidence-informed decisions (EC), while also deepening their sense of connection, responsibility, and self-identification in relation to nature (EI). This pathway illustrates how trans-contextual sequencing within TCUSSI—implemented through SSI learning in Our World—is theorized to foster integrated growth in EC and EI.

Methodology

Participants

Participants were 32 Grade 8 students from a district-level secondary school in Lampang Province, Thailand, selected purposively to reflect typical academic backgrounds and local living contexts.

Instruments

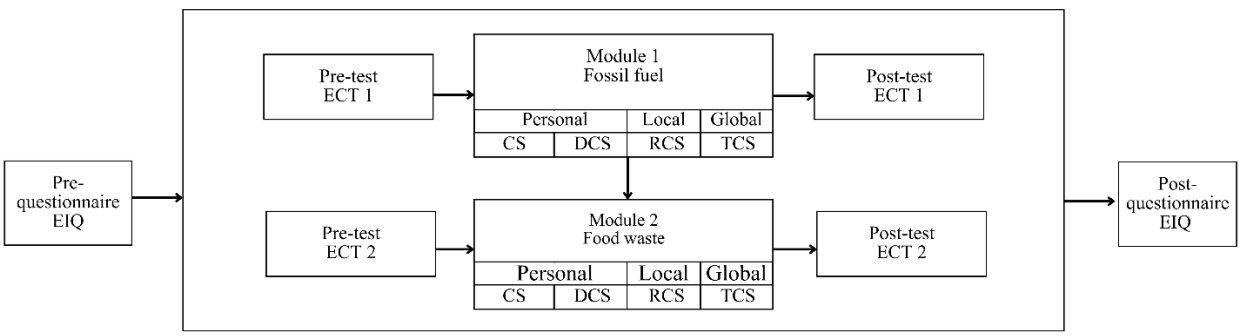
This study used three instruments. EC were assessed using an Environmental Competencies Test (ECT) consisting of two parallel 3-item forms (fossil fuels; food waste) adapted from PISA-style tasks (12 points per form; 24 points in total). EI were measured using a 24-item Environmental Identities Questionnaire (EIQ), a 5-point Likert scale adapted from Clayton (2003). Reflective journals were used to capture students' evolving ideas and experiences.

All instruments were expert-reviewed for content validity and alignment, and items were screened using IOC (≥ 0.67; Turner & Carlson, 2003). While all six ECT items met the criterion, Item 3 in both forms was revised from multiple-choice to open-ended to better elicit real-world actions aligned with EC. EIQ items below the IOC criterion were removed and wording refined for Grade 8 appropriateness. The EIQ demonstrated excellent internal consistency in a pilot test ($\alpha = .927$; Taber, 2018).

Data Collection And Analysis

Data were collected across two TCUSSI modules. For Module 1 (Fossil Fuels), students completed the EIQ and ECT pre-test, followed by the ECT post-test after 6 class hours. For Module 2 (Food Waste), students completed the second ECT pre-test and post-test after another 6 class hours, and the EIQ was administered again after both modules. Quantitative data were analysed using descriptive statistics, Wilcoxon signed-rank tests, and Spearman's rho. Qualitative data from open-ended ECT responses and journals were thematically coded (Creswell, 2014).

Figure 2. Data Collection Procedure.



Ethical Considerations

This study was approved by the Chiang Mai University Research Ethics Committee (CMUREC No. 68/144; COA No. 165/68) through an expedited review process. All participants and their legal guardians provided informed consent after receiving detailed information about the study's objectives, procedures, and their right to withdraw at any stage without penalty. To ensure confidentiality, all data were collected and reported in aggregated form, and no personally identifiable information was disclosed. Photography or video recordings were limited to group learning activities and were conducted only with explicit permission from participants and their guardians. In accordance with institutional research ethics guidelines, all research materials and data will be securely stored and destroyed within three years after publication.

Results

Effects Of The TCUSSI Learning Process On Grade 8 Students' EC

Components of EC	Pre-test		Post-test		Mean difference	Statistic	p-value	Interpretation	Effect Size	Interpretation
	Mean	S.D.	Mean	S.D.						
1. Explain the impact of human interactions with Earth's systems	4.09	1.47	5.44	1.52	1.50	370[a]	<.001*	Significant	.699	Large Effect
2. Make informed decisions to act based on evaluation of diverse sources of evidence and application of creative and systems thinking to regenerate and sustain the environment	7.28	2.84	12.75	2.65	6.00	488[a]	<.001*	Significant	.968	Large Effect
3. Demonstrate respect for diverse perspectives, and hope, in seeking solutions to socio-ecological crises	15.10	3.17	16.40	2.73	2.00	224[a]	.009*	Significant	.620	Large Effect

Table 1. Descriptive Statistics and Wilcoxon Signed-Rank Test of EC before and after TCUSSI Participation

Note: 1. *p < .05 2. Effect size interpreted according to Cohen (1988): .00 – .09 negligible, .10 – .29 small, .30 – .49 medium, ≥ 0.50 large

After participating in TCUSSI, students showed significant improvement in all three EC components. They demonstrated a stronger understanding of human impacts on Earth's systems, with a large effect size. The greatest gain was in their ability to make informed and creative decisions for sustainability, which showed a large effect. Respect for diverse perspectives and hopeful engagement with socio-ecological problems also increased significantly. Overall, TCUSSI produced strong, meaningful gains in students' environmental competencies.

Influence Of TCUSSI On Grade 8 Students' EI

Table 2. Descriptive Statistics and Wilcoxon Signed-Rank Test of EI before and after TCUSSI Participation.

Components of EI	Pre-test		Post-test		Mean difference	Statistic	p-value	Interpretation	Effect Size	Interpretation
	Mean	S.D.	Mean	S.D.						
The importance of an individual's interactions with nature	13.50	3.10	14.50	2.27	2.00	142[a]	.014*	Significant	.661	Large Effect
Self-identification	17.30	3.94	18.60	3.07	1.50	285[a]	.005*	Significant	.621	Large Effect
Ideology	13.2	2.91	14.40	2.56	2.00	233[a]	.018*	Significant	.553	Large Effect
Positive emotions	17.80	4.14	18.60	3.46	1.00	230[a]	.169	Not Significant	.311	Medium Effect
Autobiographical component	7.09	1.89	7.59	1.56	1.00	190[a]	.038*	Significant	.498	Medium Effect

Note: 1. *p < .05 2. Effect size interpreted according to Cohen (1988): .00 – .09 negligible, .10 – .29 small, .30 – .49 medium, ≥ 0.50 large.

TCUSSI led to significant improvement in four of the five EI components. Students strengthened their sense of connection to nature, environmental self-identification, and ideology, all with large effect sizes. The autobiographical component also increased significantly with a moderate effect. Although positive emotions toward nature did not significantly change, it still showed a modest improvement. Overall, TCUSSI effectively enhanced students' identity-based engagement with the environment.

Relationship Between EC And EI Following TCUSSI Participation

Before TCUSSI, EC and EI were not significantly related. After the intervention, the correlation became moderate and statistically significant, indicating that students who developed stronger environmental identities also demonstrated higher environmental competencies. This suggests that TCUSSI fosters a connected growth between what students know/do and who they perceive themselves to be regarding the environment.

Variables	ρ (Spearman's rho)	Test Statistic	p-value	Interpretation
EI (Pre-test) and EC (Pre-test)	.21	1.17	.25	Not Significant
EI (Post-test) and EC (Post-test)	.46	2.86	.01*	Significant

Table 3. Spearman's Rank Correlation between EC and EI Scores before and after TCUSSI Participation.

Note: *p < .05

At the same time, the students proposed diverse solution pathways. They emphasized reducing and phasing out fossil fuel use, shifting to renewable and clean energy (solar, wind, biomass, hydrogen), conserving energy in daily life, and adopting circular-economy practices such as recycling, reusing, repairing, composting, and reprocessing leftovers. They also valued local wisdom in food preservation as a way to extend shelf life and reduce food waste. Yet, their proposals were mostly qualitative: students rarely used quantitative evidence such as carbon footprints or cost–benefit considerations, and they seldom analysed trade-offs among different options. Moreover, while many expressed intentions to "eat just enough", "finish all food", save electricity, use cloth bags, or choose sustainable travel modes, some students admitted that they were unlikely to change their behaviour despite understanding the impacts, revealing a gap between awareness and action.

Across the reflections, worksheets, and creative products, the data strongly indicate the emergence of environmental identity and youth agency. Students described feelings of peace, happiness, and attachment when in natural places and expressed a desire to protect these environments. Experiences of environmental degradation, especially around the coal mine, triggered concern and a sense of injustice, which motivated them to "take care of nature together". Through letters to their past and future selves and Fossil Fuel Comics, they showed guilt about past behaviours but also a clear commitment to becoming people who use energy wisely and live more sustainably. They increasingly recognized that environmental problems require shared responsibility and systemic change, not just individual actions. Students called for collaboration among government, communities, schools, and households; for listening to community voices; for transparent monitoring of large projects; and for stronger policies and laws, inspired by international examples such as France's anti–food waste legislation. At the same time, they realistically acknowledged challenges in the transition to 100% renewable energy, including technological, financial, infrastructural, and political–economic constraints.

Conclusion And Discussion

The findings indicate that TCUSSI substantially enhanced students' environmental learning across cognitive, affective, and identity-based dimensions. By engaging students with SSI contexts grounded in everyday life, the intervention enabled them to situate global sustainability challenges within local realities—particularly fossil fuels, coal mining, food systems, and carbon footprints—thereby strengthening the relevance and coherence of their learning experiences. Quantitative results show significant improvements across all EC components with large effect sizes, including clearer understanding of human–Earth system interactions and stronger evidence-based, creative, and systems-oriented decision-making for sustainability. EI also increased significantly in four of five components, especially connection to nature, environmental self-identification, and ideology. However, positive emotions toward nature did not show a clear change. This may reflect a ceiling effect, as students already held relatively positive feelings

toward nature prior to the intervention, and because affective development often requires longer-term, repeated, and more embodied experiences in natural settings than a classroom-based SSI sequence can typically provide. Importantly, the moderate post-intervention correlation between EC and EI—absent at pre-test—suggests that TCUSSI aligned students' developing competencies with their environmental self-concept.

These outcomes provide empirical and theoretical support for TCUSSI as a response to limitations reported in context-based and SSI-oriented science education. Real-world contexts may enhance relevance yet remain bounded within classroom understanding, with weak links to societal engagement (Fensham, 2009; Swirski et al., 2018). Likewise, SSI pedagogy can strengthen argumentation and ethical reasoning but still struggle to bridge classroom decision-making and real-world action (Sadler, 2011; Zeidler et al., 2009). In contrast, the findings suggest that explicit trans-contextualization—sequencing learning across micro (personal), meso (local), and macro (global) contexts—helps address this gap by enabling learners to revisit the same SSI with increasing systemic complexity and civic relevance. Across contexts, students increasingly framed fossil fuels and food waste as interconnected socio-ecological systems requiring collective responses, supporting the shift from science through education toward education through science, where societal relevance and citizen engagement become central outcomes (Holbrook & Rannikmäe, 2007; Holbrook, 2010).

The significant gains in EC, particularly in evidence-based and creative decision-making, indicate that TCUSSI operationalizes key competencies emphasized in the PISA 2025 Science Framework, including systems thinking and informed action in the Anthropocene (OECD, 2023). This addresses concerns that SSI reasoning may remain largely qualitative or opinion-based, with limited integration of evidence and systemic analysis (Hodson, 1999; Yacoubian & Khishfe, 2018). Qualitative evidence further corroborates students' internalization of SSI related to fossil fuel use, air pollution, coal mining, food waste, and carbon-intensive diets, alongside proposed solutions such as renewable energy, energy conservation, circular-economy practices, traditional food preservation, and community-based waste management. However, many responses still lacked quantitative evaluation and explicit trade-off analysis, underscoring the need for stronger scaffolding in analytic reasoning.

A further contribution lies in clarifying the relationship between competence development and identity formation. Although EI has been widely recognized as influencing pro-environmental concern and behaviour (Clayton, 2003; Green et al., 2016), empirical work connecting identity development to competence-based science frameworks remains limited. The post-intervention EC–EI correlation suggests that TCUSSI may better integrate these outcomes, responding to calls to connect identity and competence that have often been treated as parallel but weakly related in environmental education (Hinds & Sparks, 2008; Lou & Li, 2021). Qualitative findings reinforce this interpretation through students' expressions of emotional attachment to nature, heightened moral concern, and growing responsibility, consistent with strengthened EI.

At the same time, qualitative data reveal an awareness–action tension: some students recognized environmental impacts yet expressed reluctance to change behaviour. Rather than signaling failure, this pattern reflects socio-scientific reasoning that acknowledges technological, economic, and political constraints on sustainability transitions, consistent with accounts of mature SSI engagement emphasizing uncertainty, trade-offs, and power relations (Sadler, 2011; Levinson, 2018). In this sense, TCUSSI appears to support not only action-oriented thinking but also adaptive capacity, which is crucial under rapid socio-environmental change.

Overall, TCUSSI proved effective in strengthening EC, EI, and early systems thinking, while addressing a key research gap by showing how trans-contextual SSI learning can integrate

competencies, identity, and emerging agency within a coherent pedagogical model. Consistent with active informed citizenry, the findings suggest that TCUSSI moves beyond preparing informed individuals toward fostering learners who can locate themselves within complex socio-environmental systems and reflect critically on their roles in societal transformation (Holbrook, 2010; Chowdhury et al., 2020). Future work should strengthen scaffolding for quantitative reasoning, systemic trade-off analysis, and behaviour–intention alignment to deepen students' capacity to engage meaningfully with complex socio-scientific issues.

Acknowledgement

We gratefully acknowledge the support of Chiang Mai University and the Faculty of Education. We also thank the participating students and their guardians, as well as the school staff, for their cooperation throughout the study. Finally, we appreciate all individuals who provided support and encouragement during the research process.

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Section: Getting Engaged With Nature And Environment

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Children's Connection to Nature: Do Forest Schools Make a Difference?

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In times of global environmental unsustainability, there is growing advocacy for reconnecting people, especially children, with nature towards countering current environmental problems. With increasingly urban lifestyles, people spend most of their time indoors, leading to a growing disconnection from nature. Children, especially, are losing opportunities to be outside and engage in nature. Contemporary environmental issues are linked to this human-nature disconnect. Forest Schools (FS) hold significant potential to address these issues. A tenet of FS is that learning in nature is not sporadic but regular and continual. Correspondingly, one objective of FS is cultivating connection-to-nature and fostering a sense-of-concern and responsibility for the environment. This study addresses a gap in empirical literature - do children attending FS differ in their connection-to-nature than those who learn in traditional non-Forest school settings? Employing three different tools (previously used with children)- a close ended questionnaire and two visual tools, this studied compared cognitive, affective, experiential, and behavioural aspects of the psychological construct connection-to-nature between primary schoolchildren who learn in two FS and those who learn in a traditional non-FS. Results clearly show that FS children have a stronger emotional connection-to-nature, they comprehend more the importance of the natural environment and have greater intention for pro-environmental behaviours compared to their traditional school peers. FS children identify nature as part of their personal identity in contrast to non-FS children, and wild nature stands out as their most preferred place for playing. This study provides direct evidence that learning in FSs enhances children's connection to nature.

Keywords: Forest School, Connection to Nature, Primary School Children

Introduction

In the context of global environmental unsustainability, fostering a connection between people and nature has become increasingly critical towards countering current environmental problems. With increasingly urban lifestyles in an industrialized technology-driven world, people spend the bulk of their time indoors, leading to a growing disconnection from nature. Children, especially, are losing opportunities to be outside and engage in nature. Contemporary environmental issues are linked to this disconnection from nature. Ecologist Aldo Leopold, already in 1949, argued that when individuals perceive the "land" as a commodity rather than identifying themselves part of it, respect for the environment diminishes, ultimately leading to its careless exploitation. Research supports that nature-connectedness is a critical psychological driver providing intrinsic motivation for environmentally responsible behaviour in adults (Frantz & Mayer, 2014; Nisbett et al., 2009) and in children (Otto & Pensini, 2017).

Nature connectedness (also termed connection to nature or nature connection) is a multidimensional psychological construct illustrating positive human-nature relationships, with cognitive, affective, experiential and behavioural aspects (Frantz & Mayer, 2014; Nisbett et al., 2009; Schultz, 2002).

Since connection-to-nature can be nurtured through direct interaction with nature, frequent and prolonged immersion in nature is more likely to influence ecological behaviours compared to

brief and sporadic encounters (Otto & Pensini, 2017). More access and experience of young people in nature reflects higher levels of nature connection (Barrable & Booth, 2020; Cheng & Monroe, 2012), while lower levels of childhood nature connection are related to increased time indoors, with digital entertainment (Larson et al., 2019). Two main driving forces for connecting children with nature are the importance for their wellbeing (O'brien, 2009) and environmental conservation, the latter grounded in connection-to-nature as a motivational factor to pro-environmental behaviour.

This study addresses the role of Forest Schools (FS) in enhancing children's connection-to-nature. Forest School Education is a distinctive educational approach that utilizes forest/woodland settings as an immersive environments for deeper more holistic learning experiences. As a specific subfield within outdoor environmental education, FS supports the overarching goals of environmental education (Grimm et al., 2011; Tal et al., 2023). The FS approach builds on the wide range of cognitive, affective, physical, interpersonal and behavioural benefits of learning outdoors (O'brien, 2009). A basic principle of this approach is that learning within natural environments occurs regularly and repeatedly, and is linked to the national curriculum (FSA, 2021; O'brien, 2009). With increasing concerns regarding children's disconnect from nature and the implications of the consequential lack of familiarity and appreciation of the natural world on their likeliness to care for their world and adopt pro-environmental behaviours, FS hold significant potential to address these issues. Emerging from the Scandinavian tradition of outdoor kindergartens, FSs have gained popularity in primary schools across Europe and North America (Harris, 2017).

An objective of FS is to cultivate a connection-to-nature and foster a sense-of-concern and responsibility for the environment (Grimm et al., 2011). Hence, while it is presumed that FS will enhance children's connection-to-nature, empirical evidence that learning in a FS promotes this attribute is lacking. Although studies have investigated children's connection-to-nature (Chawla, 2020; Cheng & Monroe, 2012; Larson et al., 2011; Otto & Pensini, 2017; Richardson, 2019), evidence directly linking FS participation and increased nature connectedness is wanting. This study responds to this gap. It explored whether children attending a FS differ in their connection-to-nature compared to those in traditional non-Forest school settings. This study forms part of a broader research examining the FS approach in Israel. The study was conducted in two of the three FS that existed in Israel.

Methodology

Research Settings And Participants

The study was conducted in three primary schools- two FSs (further termed YR and BY) and one traditional non-Forest School (further termed NH), all situated in rural communities and serving communities with similar socio-economic attributes. The participating FSs comprise two of the three existing FSs in the country. In them learning is fully outdoors, in nearby woodland adjacent to a local nature reserve. They are relatively young, growing schools, and consequently are smaller than the reference school. Participating students were from middle (3rd grade, 8-9 years old) to upper grades (5th grade, 10-11 years old) ensuring the study is conducted with children who have experienced learning in a FS. All students in each grade participated, except for the reference fifth grade, in which half of the classes participated. The research population comprised 104 FS students and 87 non-FS students.

Instrumentation

The study employed three instruments that have been found suitable for children.

Questionnaire

The questionnaire comprised two validated questionnaires previously employed with children. (1) The Nature Connection Index (NCI) (Richardson, 2019) addresses different aspects of a sense-of-connectedness to nature; (2) The Children's Environmental Perception Scale (CEPS) (Larson et al., 2011) assesses two components reflecting ecological appreciation and environmental concern: Eco-affinity (interest in nature and intentions to engage in pro-environmental behaviour) and Eco-awareness (cognitive grasp of environmental issues related to ecological sustainability). The questionnaire was translated into Hebrew and slightly adapted for Israeli children. Internal reliability of the whole questionnaire and its sections ranged between 0.84-0.93.

Inclusion Of Nature In Self (INS)

This visual scale (Shultz, 2002) assesses the extent to which individuals identify nature as part of their personal identity by a series of two overlapping circles- "Self"/"Nature". The greater the overlap, the greater the inclusion-of-nature-in-self. Participants selected the extent of overlap that best describes them.

Photographs Of Play Settings

This visual tool, adapted from Shepardson (2005), employs a series of five photographs of children playing in different settings ranging from indoor and technological to untamed natural environment: indoor digital games, urban street, urban playground, cultivated woodland, natural woodland. Participants selected in which settings they prefer most to play and feel most comfortable.

Data Collection

The researcher administered the tools accompanied by the class teacher. In the reference school, the tools were administered in the classroom, in the forest schools - outside.

Data Analysis

Due to the small number of students in each grade in the FSs, data were aggregated from the three levels. ANOVA and Scheffe Post Hoc examined differences among students from each school. For the visual tools, the frequency of each option was calculated and Chi squared for independence examined for differences in the distribution among students from each school.

Ethics Statement

The study was approved by the Chief Scientist, Ministry of Education. Data collection from the students received parental approval and was fully coordinated with the school administration.

Results

Connection-To-Nature Questionnaire

No significant differences were found between the two FS. FS students scored higher in all connection-to-nature measures and standard deviations were smaller (Table 1). They exhibit stronger emotional connection-to-nature (NCI), comprehend more the importance of the natural environment (Eco-Awareness) and have greater intention for pro-environmental behaviours (Eco-Affinity) compared to their peers in the traditional school.

Table 1. Comparison of connection-to-nature variables between children who learn in FS and those who learn in a traditional school.

Connection-to-nature variable	Mean ± SD		F-value	Significance
	Forest Schools (n=85)	Reference School (n=94)		
NCI	3.75±1.01	3.30±1.28		
Eco-Awareness	4.58±0.84	3.92±1.34		
Eco-Affinity	3.94±1.13	3.31±1.42		
Total mean	4.10±1.07	3.51±1.39	33.74	<.001

Inclusion Of Nature In Self

No differences were found in the extent of inclusion-of-nature-in-self between the FSs. FS children identify nature as part of their personal identity: the greater the self/nature overlap, the higher the percentage of children that chose this option. In contrast, children in the traditional non-FS displayed a distribution among options, with no clear trend in the extent to which they include nature as part of their self-identity (Table 2).

Table 2. Comparison of the distribution (%) of choices of Inclusion-in-Self (INS) between children in FSs and the traditional school.

Group	Self/Nature fully separated	Self/Nature small overlap	Self/Nature extensive overlap	Self/Nature fully overlapped	Chi Square test		
					Chi value	df	significance
FSs	2.30	14.94	37.93	44,83	22.72	3	<.001
Ref school	15.38	31.73	17.31	35.38			

Preferred Play Environment

No differences were found in the preferred play settings between the FSs. FS children showed significant differences from their traditional school peers in their preferred play settings. Untamed nature stood out as the favoured play settings of FS children (>70%), while preference for playing in nature and indoor multimedia games was similar in non-FS children (Table 3).

Discussion

There is growing advocacy for reconnecting people, especially children, with nature to promote environmental sustainability. FS– long-term outdoor learning settings- have gained recognition as a significant way to foster this connection. This study addresses a gap in the research concerning the influence of FS on children's connection-to-nature. To tap into the different psychological aspects of connection-to-nature, this study employed multiple visual and textual tools. Despite the limited sample size (reflecting small numbers of children in the participating schools), the findings highlight that FS children exhibit a deeper and more significant connection-to-nature than their traditional school counterparts. FS children demonstrate a stronger emotional bond and sense of belonging to the natural world (NCI). They include nature-in-self reflecting

that their connectedness encompasses care and commitment to nature (Schultz, 2002). They express more cognitive understanding of the importance of nature (Eco-Awareness) and greater intention for involvement in pro-environmental action (Eco-Affinity). These findings align with research indicating that connection-to-nature promotes pro-environmental behaviours in children (Otto & Pensini, 2017). Expectedly, both groups enjoy multimedia games, which are identified a key factor associated with declining nature-based outdoor time for youth (Larson et al., 2019), but FS children clearly prefer playing outdoors in wild nature to indoor multimedia entertainment. In conclusion, this study provides direct evidence that learning in a FS enhances children's connection-to-nature.

Table 3. Comparison of the distribution (%) of the participants' preferred play settings between children in FS and those in the traditional school.

Group	Digital game indoors	Urban street	Urban play-ground	Cultivated woodland	Natural woodland	Chi Square test		
						Chi value	df	significance
FSs	16.09	2.30	8.05	2.30	71.26	15.21	4	.004
Ref-school	38.46	2.88	11.54	2.88	44.23			

Acknowledgement

The authors thank the schools' administration and the students who participated in this study.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Empowering Pupils To Explore Urban Environments. Identifying Contexts For Environmental Sensing Using Non-Functional Prototyping.

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When engaging in outdoor activities in public places, school pupils are exposed to environmental conditions such as heat and noise, as well as pollutants like particulate matter. This work investigates how school pupils can be made aware of these conditions, learn about their background, and reflect on the connection between outdoor activities and environmental conditions by enabling children to design non-functional, context-based environmental sensor artifacts in a three-stage workshop. A participatory workshop setting is introduced that identifies and describes the contexts of school pupils' outdoor activities as well as relevant measured variables in these contexts. Furthermore, school pupils design prototypes for environmental sensor artifacts using creative materials such as fabrics, cardboard, and dummy electronic components. Results from three workshops with 57 pupils reveal contexts in which environmental sensing can be applied, and environmental education can be connected to their personal interests and daily routines. The workshop results include non-functional prototypes as the basis for further design steps toward functional environmental sensor artifacts. Feedback from practitioners and experts provides valuable insights into enhancing the workshop setting and its materials. The study contributes a structured participatory design approach that bridges pupils' lived outdoor practices with environmental sensing concepts in lower secondary STEAM education. The outcome of our approach demonstrates how environmental education and the impact of environmental conditions on the realities faced by school pupils can be applied in STEAM education.

Keywords: Environmental Education, Classroom Research, STEM Education

Introduction

Climate change and its negative impacts on the environment are among the most significant challenges facing the world today. This particularly affects urban areas, where, for example, air pollution, higher anthropogenic waste, heat, and poor outdoor thermal comfort lead to overheating and poor air quality (IPCC, 2023). Children are directly exposed to these pollutants when being active in public spaces. This work investigates how pupils can be empowered to explore urban areas they frequently use by identifying contexts of outdoor activities and measured variables relevant to 10-14-year-old children. Therefore, non-functional environmental sensor artifacts are designed in participatory classroom workshops. The work is aligned with Austrian educational goals, where pupils learn to describe applications of technology in the environment and society using interdisciplinary examples and consider their relevance for social groups and cultural contexts (BGBl., 2022), the European sustainability competence framework GreenComp (Bianchi et al., 2022), as well as with the United Nations Sustainable Development Goal 13.3, which aims to improve education and awareness-raising on climate change mitigation (United Nations, 2016). The Austrian curriculum does not include subject-specific computer science teaching at this age. STEAM subjects provide the educational foundation for this work, as they combine science, technology, engineering, and the arts. Many educational materials, projects, products, and technologies have emerged in recent years to support pupils in learning to code (*Scratch - Imagine, Program, Share*, 2024), assemble robots (*Micro*, 2024), and experiment with

environmental sensors (*senseBox*, 2023). The focus of these solutions is on helping children understand complex technology. While numerous educational tools introduce pupils to environmental sensors, little is known about how pupils themselves contextualize environmental sensing within their everyday outdoor practices. This study addresses the gap by engaging pupils as active designers of environmental sensing artifacts grounded in their own outdoor activities. Through participatory, non-functional prototyping, pupils identify relevant contexts, environmental influences, and measurable variables connected to their everyday experiences in urban environments. To better understand how environmental sensing can be meaningfully embedded in pupils' lived experiences, this study investigates the following research questions:

RQ1: How do pupils conceptualize the relationship between their everyday outdoor activities, perceived environmental conditions, and measurable environmental variables within a participatory design process?

RQ2: How are these conceptualizations materialized in pupils' non-functional prototypes of environmental sensing artifacts?

Theoretical framework

Contextual Design (CD) integrates user-centred techniques into the development of software and hardware systems and, therefore, focuses on users and their practices (Beyer & Holtzblatt, 1997). CD aims to design "a new and better way for users to live their lives, achieve their intents, touch the people that matter to them, and perform their activities by introducing better tools and systems." (Holtzblatt & Beyer, 2015). While CD ensures that the resulting artifacts are aligned with the user's context, *Participatory Design* (PD) integrates users as contributors to the entire design process. The design process is realized as a partnership between implementers and users (Schuler & Namioka, 1993). Musaeus et al. (2024) apply PD to design learning tools involving teachers, researchers, and developers to overcome challenges in computing education in high schools. Morais et al. (2022) present a theoretical model for children's participation, including typologies and roles in a PD process. The model serves as a theoretical foundation, supporting the planning of activities and methods in the design process. Iivari et al. (2024) follow a PD approach that includes activism education to enable PD that matters, meaning the PD process must address significant societal issues that matter to people. *Participatory urbanism* describes the involvement of citizens in research activities and "promotes new styles and methods for individual citizens to become proactive in their involvement with their city, neighbourhood, and urban self-reflexivity" (Paulos et al., 2008). Participatory urbanism enables a better understanding of, e.g., air quality through the use of low-cost hardware and higher-resolution data for an area (Miskell et al., 2017). Benavides Lahnstein et al. (2022) investigated young people's participation in citizen science programs and called for enhancing their opportunities to participate and position themselves as actors in authentic scientific initiatives. The GreenComp framework defines sustainability as "prioritizing the needs of all life forms and of the planet by ensuring that human activity does not exceed planetary boundaries" and refers to sustainable development as processes to stimulate or achieve progress in sustainable ways (Bianchi et al., 2022). Henke & Elster (2022) introduce guiding principles to promote action competence in the context of education for sustainable development in schools, following a design-based research approach. Citizen participation in collecting environmental data is implemented in various ways. Helbig et al. (2021) provide a comprehensive overview of scientific projects that utilize wearable sensors, for example. From these approaches, we derive three guiding principles for a workshop design: contextual anchoring in everyday practices, shared control in design decisions, and materialized reflection through prototyping.

Method

The study follows a participatory design approach with children, drawing on cooperative inquiry and low-fidelity prototyping traditions (Druin, 1999, 2002). These approaches are particularly suited to exploring children's perspectives on technology and environmental phenomena, as they support expression beyond verbal articulation. Hagen et al. (2012) introduce a method matrix for designing with children and aligning them with specific activities in the design process, such as the "bags of stuff" method for low-tech prototyping. The bags of stuff represent a collection of materials, including paper, scissors, glue, markers, etc., used to create technology prototypes in response to specific questions, maintaining focus on the design task (Knudtzon et al., 2003). Based on these principles, a three-stage workshop was developed to elicit 10-14-year-old pupils' outdoor activity contexts, relevant environmental variables, and design ideas for environmental sensing artifacts.

Workshop Stage 1: The Context Of Outdoor Activities

The first stage of the workshop focuses on eliciting pupils' everyday outdoor activities and the contexts in which these activities take place. Using a structured template, participants describe their outdoor activities by outlining the activities themselves, required items, modes of mobility, and the social setting. This information provides insights into pupils' lived outdoor practices and the situational conditions under which environmental sensing could potentially be integrated. Pupils talk about their experiences and how they relate to their surroundings in the following phase. Based on their perceptions and observations, they identify specific environmental elements that caught their attention during these activities. To convey these observations, they employ evocative language. This step is intended to document their preliminary, experience-based comprehension of environmental conditions prior to delving into more formal methods of measurement. This initial phase lays the groundwork for later workshop sections by gathering qualitative data regarding the contexts of the pupils' activities and their sensory experiences.

Workshop Stage 2: Environmental Data And Measured Variables

The second stage of the workshop is all about linking what pupils notice in their environment to actual things that can be measured. Building on the sensory experiences from the first stage, pupils explore common environmental factors important in urban settings, such as temperature, noise, and air quality. In this part of the workshop, pupils acquire basic knowledge of the most common measured values and distinguish which can be experienced through their senses and which require a specific tool for detection. After this introduction, participants add measured variables to the ones they named earlier and generate a richer picture of possibilities for measuring relevant environmental data. To conclude this stage, participants reflect on possible effects caused by the identified environmental influences and formulate concrete ideas for reducing these effects.

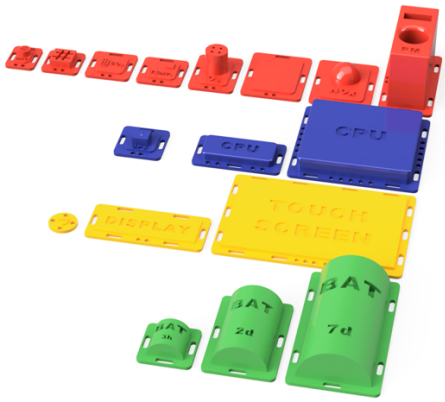
Workshop Stage 3: Designing An Environmental Sensor For A Specific Context

In this stage, pupils design and create individual non-functional environmental sensor prototypes. The design of the artifacts is supposed to address the previously defined criteria of an outdoor activity and the identified environmental influences. Therefore, participants use dummies for electronic and sensor components, as shown in Figure 1. These components are intentionally aligned with real-world technical counterparts to introduce basic technical constraints without requiring functional implementation.

The prototyping process aims to support materialized reflection on how environmental data collection and feedback could be embedded in pupils' everyday outdoor practices. At the end of

the workshop, participants present their results, explain their design, and provide reasoning for their design decisions. This stage generates qualitative data on pupils' conceptualizations of environmental sensing and the role of material prototyping in linking everyday contexts with abstract measurement concepts.

Figure 1: 3D printed sensor dummies for technical components. (red = sensors, blue = microcontrollers and GPU module, yellow = output components, green = power supply).



Data Collection And Analysis

Data were collected through the templates participants used to describe their outdoor activities, note the environmental influences they experienced, document the actions they envisioned to mitigate negative effects, and through the resulting prototypes. The workshop's design stage was video-recorded. These records were used to analyse the design process the participants followed and the design decisions they made. This wide variety of collected data enabled data triangulation (Flick, 2011) to yield comprehensible insights into participants' conduct and resulting designs. Data were analysed thematically (Braun & Clarke, 2006), and the resulting themes are aligned with the stages of the workshop and the single tasks. The resulting prototypes, their functionality, and included measured variables were tracked back to the initial descriptions of outdoor activities, needed items, modes of transport, and relevant measured variables to identify how the results correspond with the initially described context and which new factors emerged during the design stage. The workshop design and its materials were discussed in semi-structured expert interviews (Meuser & Nagel, 1991), which included a teacher (IP1), a researcher in the field of learning technologies and eDidactics (IP2), and a researcher and teacher educator covering the fields of health and environmental education (IP3). The expert interviews were video recorded, transcribed, and analysed thematically.

Results

The results are based on data collected during three workshops with 57 participants across three different schools in Vienna, Austria. The participants are aged 10-14 years and have not received subject-specific computer science teaching. The analysis focuses on patterns across activity contexts, environmental perceptions, and design concepts.

Contexts of outdoor activities

Analysis of the activity descriptions revealed dominant themes in pupils' everyday outdoor practices. A large proportion of activities were related to sports and physically active leisure, including both organized sports and informal play. Swimming for leisure, ice skating, and various ball games were highly referenced by the participants. Other referenced activities reflect

participants' transitional and social activities, often including their friends and relatives, such as relaxing, going for a walk, sitting in the park, and shopping.

The referenced activities were associated with items participants regularly use during their outdoor activities. Various types of bags, backpacks, and other carrying aids were referenced, as well as drinking bottles and nutritional supplements. Leisure and sports equipment, such as balls, rackets, skates, specific clothing, and other sports gear, was assigned to the theme of physical activity. Money was highly referenced to be a relevant item for outdoor activities, as well as the (smart)phone for communicating with others. Skateparks, soccer goals, and other infrastructure were mentioned as relevant, as well as proper conditions such as nice weather. Regarding their mobility, participants identified walking, cycling, riding a scooter, being driven by car, and using public transportation as the most relevant options.

When asked about their perception through their physical senses, participants most frequently referenced their sports equipment and temperature in relation to their sense of touch. Regarding their sense of smell, nature was highly referenced, and for their auditory sense, they referenced various animals, people, and sports equipment, such as the sound of hitting a ball.

From Physical Senses To Measured Variables

In addition to phenomena participants perceived with their physical senses, they reflected on specific measured values relevant to their outdoor activity. Weather and air quality variables were identified, including temperature, wind speed, particulate matter, CO_2, and light intensity. Noise was mainly referenced as general noise, rather than noise from specific sources. In the theme of soil & water, soil moisture and water quality were referenced. Traffic-related references include vehicle count and vibrations caused by vehicles. Many references include values that do not address environmental measures in any sense, such as the velocity of a soccer ball or a bike ride, but are closely related to the outdoor activities of the participants.

Participants reflected on potential actions to improve the conditions of their outdoor activities. Requests for regulations include implementing threshold values for pollutants. Improvements of conditions require reducing noise and improving water quality. Regarding transport, having fewer cars and fewer cargo ships is desired. Ideas for enhancing public infrastructure include additional greenery and increased shading. Actions that describe individual behaviour address proper nutrition and hydration, as well as the use of earplugs to reduce noise exposure.

The second stage of the workshop demonstrates how environmental conditions can be measured using specific sensors and identifies the relevant measured variables. It clearly shows that, in addition to environmental measures, participants are highly interested in measures directly related to their outdoor activity, such as the speed of a soccer ball.

Context-Based Designs Of Environmental Sensing Devices

In the third stage of the workshop, participants were tasked with designing and creating a sensor prototype for an outdoor activity, working in groups of three to five pupils using the available materials and tools. This design and prototyping stage produced 24 non-functional prototypes for environmental sensors. Three distinct patterns were found, as illustrated in Figure 2.

The first design pattern features wearable sensors. Sensing technology is incorporated into clothing items such as hats, bracelets, and vests. These sensors continuously gather data on the wearer and provide quick feedback, linking their surroundings to their sensations. Another design pattern involves sensors embedded in activities. These sensors are incorporated into sports gear or equipment related to the activity, such as entertaining devices, bags, or training tools. This combines environmental data with activity information to illustrate how people move, their

performance levels, and their locations. The third pattern involves sensors in places or things around us. These are set up in parks, streets, or private gardens. They monitor the environment over time and are usually intended for group use rather than providing information to individuals. In every design, pupils typically combine information about the environment with their own activity. It appears that sensing the environment was more relevant in relation to people's preferences, daily activities, and social circles.

Figure 2: Examples of resulting designs: Cap with temperature sensor (wearable sensor), portable radio with temperature sensor (activity-related sensor), garden fairy lights (placed sensor).

Cross-Cutting Insights And Misalignments Across The Workshop Stage

During the three workshop stages, some recurring ideas and conflicts emerged. Many groups created sensor designs based on the activities and environmental factors they had previously identified. However, some groups started to focus more on activity or health information. In these cases, environmental sensing shifted to the background and became less closely tied to the original research. This difference highlights the conflict between allowing freedom in the design process and maintaining a strong focus on environmental sensing. The open prototyping phase encouraged creativity and engagement. However, sometimes pupils concentrated on aspects of their activities that were personally important to them rather than considering the environment in the first place. Nevertheless, these changes provide valuable insights into what motivates and interests pupils. The shift towards activity information suggests that environmental sensing is more meaningful to pupils when it relates to how they engage in activities, how they play, or what they care about. These results highlight the need for clearer transitions and reflection between workshop phases while allowing sufficient freedom. This would facilitate creative and relevant design processes.

Experts And Practitioners' Perspectives On The Workshop Design And Learning Potential

The results from the expert interviews reflect their perspectives on the *workshop setting*, its *materials*, the *resulting designs,* and *learning effects.* The experts emphasized the importance of seamless transitions between workshop stages, particularly when shifting from contextual analysis to prototype creation. They added that, without clear direction, pupils might lose focus on environmental issues and become more concerned with personal, activity-related actions. IP2 recommends using more structured templates to support transitions and maintain focus on the workshop goals. IP3 points out that gamification elements work well in this age group, and the templates could be designed like a gameboard where participants fill in information and develop ideas step by step. Regarding support, the experts noted that teachers should act as helpers, not co-designers, and that their role in the workshops should be clear. While some direction was considered beneficial for pupils' thinking and social needs, experts cautioned against teachers influencing pupils' design choices, as IP2 states: "They can supervise, and they can talk to children who are distracted doing other things and guide them back to the task, but not do the task for them. And you should try to write this down explicitly in your workshop setup." (IP2). The

experts also reviewed the workshop materials and noted that the information posters in the second part contained too much text for the targeted age group. IP3 suggests to "…simplify it. With more illustrations, I only keep the most necessary facts. […] I would insert legends." (IP3). Using more pictures and better-planned note-taking was suggested to help pupils engage with and understand the material more easily. At the same time, the use of non-working technical models was well received, as they facilitate thinking about real design without the need for functional parts, as IP1 emphasizes: "Even though they weren't real sensors, it still made it somehow realistic, or gave it a feeling of seriousness." IP1 addressed the learning effects and stated that: "I was just thinking about whether, for some children, this was perhaps the first time they had to deal with the fact that there are specific values for measurements. […] it was certainly an eye-opener for some people to learn that there are sensors for these different measured values and in which units they are measured." (IP1), but also mentioned "that for some people, this then also expired in their short-term memory" (IP1).

The feedback from experts shows that the workshop setting and its goals are well set for discussing environmental sensing and creating sensor designs in a participatory session. Additionally, the experts' perspectives reveal improvements in materials, transitions between stages, and the definition of the teachers' role.

Discussion

The findings in relation to the research questions are discussed in this section and are situated within the theoretical frameworks of context-based learning and participatory design.

Interpreted through the lens of Contextual Design (Beyer & Holtzblatt, 1997), the findings indicate that pupils conceptualize environmental sensing in close relation to their everyday contexts. Participants were not only able to name a wide range of outdoor activities, but also to identify relevant environmental factors and metrics. The environmental conditions became meaningful primarily when embedded in concrete activities such as sports, mobility, or social leisure, supporting the CD assumption that design is grounded in their lived contexts.

From a participatory design perspective, pupils' conceptualisations demonstrate how shared control shapes meaning-making processes. The workshops enabled pupils to express environmental sensing concepts through their own interests and experiences, positioning them as contributors throughout the design process. This aligns with Schuler and Namioka's (1993) understanding of participatory design processes as a partnership between designers and users.

Pupils' frequent integration of environmental and activity-related measurements can also be interpreted as participatory urbanism. Benavides Lahnstein et al. (2022) found that pupils positioned themselves as learners and actors engaged with environmental issues relevant to their immediate surroundings. Environmental sensing was therefore not viewed as a stand-alone data collection task, but rather as a means of understanding and potentially responding to environmental conditions in urban contexts.

Interesting in our research was that there were clear differences in the transition between the stages of the workshop: While stages one and two were well integrated in terms of content, the transfer of their findings to stage three was not always consistent. Several groups designed prototypes that were only partially based on the previously named activities or metrics. This suggests that additional structuring aids, such as connecting worksheets and templates, checklists, or a brief re-mapping of the previous stage, could strengthen the connection between the stages. Regarding RQ1, this indicates that the presented workshops support pupils in conceptualizing the relationship between outdoor activities and environmental conditions by facilitating structured reflection on this relationship through the workshop process and its materials. Nevertheless, there

is room for improvement regarding the transitions between stages. As well, the focus on creating environmental sensors must be maintained throughout the design phase.

In RQ2, we investigate how the relationship between outdoor activities and environmental sensing materializes in sensor designs. The non-functional prototypes demonstrate how the pupils' ideas about the relationship between outdoor activities and environmental sensing were realised through design. These artifacts serve as tangible examples of how pupils integrated environmental sensing into activity-specific contexts, rather than using it as a technical fix. This demonstrated that environmental measurements were considered important when they were directly related to pupils' daily activities.

The conversation now shifts to how pupils integrated environmental sensing ideas into their non-functional prototypes, building on these conceptualizations. The findings also highlight a fundamental conflict between developing contextually accurate and environmentally relevant sensing concepts and ensuring transparency in the participatory design process. While openness encouraged creative and varied designs, it also sometimes led to activity-related features taking precedence over environmental sensing. In a few instances, however, this focus on activities also resulted in hybrid designs that integrated activity-related and environmental measurements, demonstrating pupils' attempts to negotiate relevance within the design space.

From a participatory design perspective, this conflict reveals a key challenge: balancing personal preferences with broader societal concerns. According to the results, environmental relevance requires intentional support rather than assuming it will emerge naturally. This is consistent with Iivari et al.'s (2024) call for participatory design that addresses important issues. To facilitate design processes that reflect pupils' lived experiences and engage with relevant environmental issues, it is crucial to balance creative freedom with thematic alignment.

Limitations

Several limitations of this study need to be considered. The workshops took place in school settings with limited time and resources, and the sustainability of the learning outcomes was not systematically assessed. The results, therefore, capture their ideas and understandings at a specific moment rather than documenting lasting learning. Group dynamics, such as the presence of dominant individuals or unequal participation, may have influenced how environmental concepts were expressed in the prototypes' designs. Finally, the workshop used a predefined set of materials for non-functional prototyping. While this made the activity accessible for the age group, it may also have narrowed the range of possible designs. This reflects a common tension in participatory design: offering enough structure to support learners while allowing space for open-ended exploration.

Conclusion And Future Work

Climate change mitigation is a challenge that needs strong efforts from all parts of the global society. Education and awareness-raising on climate change and the reduction of pollutants are integrated into curricula to support children in identifying how they are affected within their cultural context. The introduced participatory workshop setting, along with its materials, enables participants to reflect on environmental conditions related to their outdoor activities by creating a context-specific environmental sensor. The resulting designs illustrate how children envision environmental sensor artifacts for their outdoor activities, and that certain combinations of measured variables, collecting data on environmental conditions and the activity itself, are a fruitful approach for supporting engagement and long-term use.

From a didactic perspective, two levels of impact can be distinguished: (1) research findings on the contextualization of environmental measurement in the everyday lives of young people, and (2) learning effects in terms of environmental awareness, interest in technology, and design competence. While methodological openness provides rich design ideas for research, a stronger connection to school subject contexts (e.g., physics, geography, biology) can be helpful for sustainable learning effects. The results suggest that measurable, sensory variables (temperature, noise level, wind) facilitate intuitive access, while more abstract variables (e.g., NO_x, ozone) require additional didactic preparation.

Overall, the study confirms the potential of participatory, context-based design workshops to promote both environmental education and technical design in lower secondary education. To optimize the workshops, it is particularly advisable to strengthen the common thread between stages in terms of content, make the materials more age-appropriate, and create opportunities for further in-depth work in the classroom. Additionally, in future work, the dummies representing technical components are to be replaced by functional parts, enabling children not only to design sensors but also to collect real-world data and draw conclusions about environmental conditions affecting their outdoor activities.

Acknowledgements

This work is conducted within the scope of the “STEAM - STEM - stART'em” doctoral program funded by OeAD (Austria's Agency for Education and Internationalisation). The workshops were supported by the grammar schools BG & BRG Rahlgasse (Vienna) and BRG Seestadt (Vienna), as well as by the middle school PMS Vienna.

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Section: Sex Education, Equality, And Menstruation

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Learning About The Menstrual Cycle Through The Use Of Narratives In Initial Teacher Education

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Human biology and health education are extremely important topics in secondary school and, by extension, in teacher education. In particular, there are several misconceptions and reductionist ideas associated with teaching and learning about the menstrual cycle. Within this framework, we set out to develop a teaching sequence to foster a comprehensive understanding of the biological and functional concepts related to the menstrual cycle. The study used a design-based research approach. The activities were implemented in an initial teacher training course in Córdoba, Argentina, focusing on creating multiple narratives about the menstrual cycle and reflecting on the stories of different characters. The results show that the pre-service teachers constructed contextualised ideas about the menstrual cycle and that the pedagogical resources developed facilitated a practical visualisation of the theoretical content, promoting the expression and questioning of notions, taboos, emotions and experiences related to this process.

Keywords: Health Education, Teacher Education, Human Biology.

Introduction

In secondary schools in Córdoba (Argentina), the biology curriculum broadly covers Human Biology, including biological systems, organs and processes. However, much of this content is complex and abstract for students, which often leads to rote learning (Ariza & Navarro, 2021). In addition, many of these topics are closely linked to health education, which requires teaching oriented towards the analysis of information, the development of critical thinking skills, reflection, problem-solving and the ability to establish relationships (Jiménez-Aleixandre & Puig, 2022).

Regarding specifically the concept of the menstrual cycle, several authors highlight the variety of misconceptions and reductionist ideas linked to this process, including approaches that focus only on reproductive aspects, notions that emphasise the uniformity of bodies, and approaches that override emotions, experiences or cultural meanings about this process (Blázquez Rodríguez & Bolaños Gallardo, 2017; Kohen, 2018; Sirovina, 2022). This view makes it difficult for students to connect the menstrual cycle to their daily lives and understand its relevance to health and well-being. Droguett Muñoz and Camacho González (2021) assert that the teaching of the menstrual cycle reflects the shortcomings of the current education system, which is not adapted to students' needs. Learning about the menstrual cycle involves understanding complex biological processes that require in-depth preparation, making it a challenging subject. In this sense, it is necessary to improve teacher training in mastering these concepts so they can teach them more deeply, avoiding simplistic explanations.

The menstrual cycle is a multidimensional phenomenon in which biological, psychological, social and cultural aspects interact. This underlines the need to analyse the psychosocial aspects of the menstrual cycle, considering not only the biological functions but also the psychological, anthropological and cultural dimensions (Botello-Hermosa & Casado-Mejía, 2015). This integration requires rethinking the teaching of the menstrual cycle so that students not only

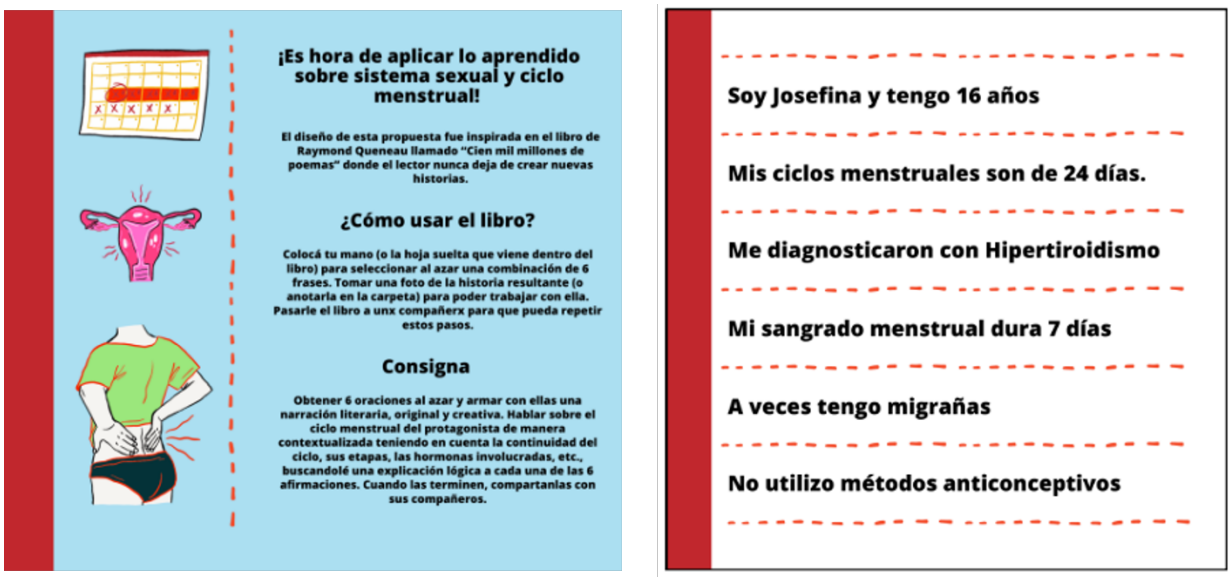
receive information but also understand its multidimensionality and apply it to specific contexts. In this sense, narratives offer the potential to convey the conceptual content of school science, contribute to meaningful understanding by relating central ideas in a plot, and positively impact student motivation, among other issues (Revel Chion & Adúriz-Bravo, 2022). This proposal seeks to stimulate student motivation and foster situated and contextualised understanding, recognising the diversity of emotions and bodies, each with unique personal experiences.

Method

The study was conducted within a design-based research approach, which aims to generate knowledge to improve teaching practices by preparing, implementing, and analysing didactic designs (Guisasola & Oliva, 2020). The didactic design aimed to promote a comprehensive understanding of the biological and functional concepts of the menstrual cycle from a holistic, multidimensional perspective. The theoretical goal was to produce evidence-based contributions to the teaching of human biology, specifically the menstrual cycle, through narratives. The proposal was carried out in collaboration with the professor responsible for the 'Human Biology' course in an initial teacher training program in Biology, with seven pre-service teachers participating in its implementation. The results were analysed qualitatively.

In this context, the didactic tool ‘One Hundred Billion Menstrual Cycles’ (Figure 1) was created (Manetti, 2023). This small book allows readers to create multiple narratives about the menstrual cycle, featuring different characters. This tool aims to promote a comprehensive understanding of the biological, social, and emotional aspects of this concept.

Figure 1. Two pages of the book designed for the development of the didactic sequence. The first page explains how to use this teaching tool. The second page represents an example of the six sentences that could be combined to create a narrative.



The first part of the intervention consisted of a theoretical introduction to the menstrual cycle, addressing its definition, duration and characteristics. The pedagogical approach prioritised critical dialogue in the classroom, supported by audiovisual tools and constant feedback. Then, the pre-service teachers created contextualised narratives with one of the book's characters as the protagonist. Finally, in a group dynamic, participants shared their stories, highlighted the common and unique points of the narratives and reflected on how to integrate this knowledge into their daily lives.

The narratives were collected to evaluate the teaching sequence and to assess the tools used. Each narrative was evaluated on four components: pragmatic, rhetorical, logical, and theoretical. Following Revel Chion et al. (2013), the pragmatic component refers to the appropriateness to

the context that gives meaning to the story, the rhetorical component implies the intention to persuade the reader or listener of the narrative, the logical component represents the complex syntactic structure of the text and the theoretical component alludes to the theoretical model of reference, in this case, the menstrual cycle.

To deepen the theoretical component, the categories of analysis proposed by Bahamonde and Gómez Galindo (2016) were restructured, and the ideas of continuity, interaction, transformation and integration present in the narratives were evaluated. The concept of continuity implies conceptualising the sexual system and folliculogenesis as the basis of the menstrual cycle. The notion of interaction emphasises that the menstrual cycle is not only dependent on the sexual system but also cuts across all systems of the organism. Transformation refers to the evolving nature of the follicle throughout the menstrual cycle. Integration involves understanding the connections between the sexual system, other bodily systems, and the emotional experiences that occur during the cycle, establishing a logical, biological and emotional explanation for the process.

Each category was assessed using a rubric developed by the researchers, with the following values assigned: excellent, satisfactory, needs improvement or insufficient. Additionally, two surveys were administered, one at the beginning and the other at the end of the development of the didactic sequence, to assess pre-service teachers' knowledge and opinions on the subject and the proposal developed.

Results

Most narratives demonstrated contextual appropriateness, structural coherence, and persuasive presentation. In terms of the theoretical component, the most prominent category was integration, with most narratives showing a clear understanding of the stages of the menstrual cycle, the hormones involved, the characteristics of different methods of contraception, and the development of a logical, biological and emotional explanation for the symptoms presented in the book (Table 1). Regarding the other three dimensions, while some narratives were auspicious, others showed insufficient development. The most challenging aspects in this regard were the following: 1) only three narratives presented the interaction between the ovarian cycle, the endometrial cycle and the hormones produced in the hypothalamus, and 2) the transformation of the follicle into an egg cell was not captured in the writings. However, during the oral exchange of the narratives, the participants demonstrated an understanding of these topics. This finding suggests that the narrative writing task could be enhanced to foster greater development in this area.

Table 1. Assessment of the theoretical component across the seven narratives, showing the distribution of qualitative ratings for continuity, interaction, transformation, and integration.

Narrative	Continuity	Interaction	Transformation	Integration
Narrative 1	Satisfactory	Needs improvement	Needs improvement	Insufficient
Narrative 2	Excellent	Needs improvement	Excellent	Excellent
Narrative 3	Needs improvement	Insufficient	Insufficient	Satisfactory
Narrative 4	Needs improvement	Excellent	Insufficient	Satisfactory
Narrative 5	Needs improvement	Excellent	Insufficient	Excellent
Narrative 6	Needs improvement	Excellent	Insufficient	Excellent
Narrative 7	Needs improvement	Insufficient	Excellent	Excellent

Beyond identifying biological elements, the analysis of the narratives revealed an integration of the menstrual cycle as a multidimensional phenomenon. Participants articulated biological processes in relation to emotional experiences, social contexts, and life trajectories of the characters they constructed. This integration was particularly evident in narratives that incorporated references to stress, identity, life stages, access to healthcare, and contraceptive decisions. Such narratives suggest that the use of contextualised storytelling facilitated a shift from a fragmented understanding of the menstrual cycle to a more situated conceptualisation.

An additional relevant outcome concerns the explicit emergence of emotions associated with the menstrual cycle. Many narratives incorporated emotional dimensions such as anxiety, relief, discomfort or ambivalence. These emotional references were not treated as mere anecdotes but were often linked to biological explanations or contextual factors, such as hormonal fluctuations, social expectations, or stressful life situations. This finding suggests that narrative-based activities may create pedagogical spaces that legitimise emotional expression and contribute to questioning socially rooted taboos surrounding menstruation.

The diversity of characters represented in the narratives constitutes another significant result. Participants constructed stories that represented individuals at different life stages and with diverse bodily and identity-related experiences, as well as individuals with irregular cycles, health conditions, or diverse reproductive choices. This diversity allowed pre-service teachers to problematise the idea of a "standard" menstrual cycle and to recognise variability as a central feature rather than an exception. In this sense, the narratives functioned as a didactic resource to challenge universalised and normative models commonly found in school biology teaching.

Regarding the surveys, most participants highlighted the usefulness of the book and the infographic for understanding the menstrual cycle. The pre-service teachers highlighted that the book "One Hundred Billion Menstrual Cycles" enables them to combine sentences to create stories, engaging in a creative and reflective exercise while applying theoretical concepts in a practical context. In addition, the comprehensive, contextualised and holistic approach enabled participants to incorporate social, cultural and emotional aspects into their narratives, enriching their understanding of the menstrual cycle as a complex and multidimensional phenomenon.

Conclusions

The results indicate that the activities proposed during the sequence, including the use of the book 'One Hundred Billion Menstrual Cycles', enriched the understanding of the menstrual cycle, providing a more comprehensive and contextualised perspective. These pedagogical resources facilitated a practical visualisation of the theoretical content, promoting the expression and questioning of notions, taboos, emotions and experiences related to the menstrual cycle and menstruating bodies. Thus, a multidimensional construction of the cycle has been promoted, encompassing physiological, social, emotional, cultural, economic and health aspects.

Besides, it is important to highlight that the book 'One Hundred Billion Menstrual Cycles' offers opportunities to explore various topics, such as sexual diversity, pregnancy, and endocrine disruptors, among others, issues that we will be able to address in new implementation cycles of our proposal within the framework of the design-based research approach.

Although the results were positive, opportunities for improvement were identified. It is suggested that the narrative task be reformulated to deepen the teacher's theoretical knowledge, thereby leading to more enriched stories. It is also proposed to include more pages in the book, as the first sentences were less frequently chosen by participants, leading to the same characters and stories being selected by different pre-service teachers. This modification aims to generate a greater variety of stories and avoid repetition of the same characters. In dialogue with the professor who

carried out the sequence, we assert that it is essential to implement the strategy across various institutions to evaluate its effectiveness in different contexts and educational levels, in order to adjust the proposal and apply it transversally throughout the education system.

Despite the promising results, this study is limited by the small number of participants and its implementation within a single institutional context. Future research could explore the use of this narrative-based approach in other teacher education settings and educational levels. Additionally, further studies could investigate how narrative work interacts with other scientific practices, such as modelling or argumentation, in the teaching of human biology.

Acknowledgement

This research was funded by Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), grant number 28720210101027CO and Secretaría de Ciencia y Tecnología de la Universidad Nacional de Córdoba (SECyT-UNC), grant number 33620230100484CB. Additionally, the authors would like to thank the course professor and the pre-service teachers who participated in the study; this work would not have been possible without their collaboration.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Exploring Adolescent Student's Knowledge and Beliefs about Menstruation and Understanding the Influence of Education on It.

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This study explores the knowledge, beliefs, and attitudes regarding menstruation among middle school students in an urban co-educational school in India. The research investigates how formal education influences students' understanding of menstruation, with a focus on dispelling myths and misconceptions. Data was collected through a survey administered to 62 students from Grades 7 and 8, with a focus on comfort levels, scientific knowledge, misconceptions, and information sources. Findings indicate that while Grade 8 students demonstrated improved awareness of menstruation compared to Grade 7 students, significant gaps remain in scientific understanding and there are persistent cultural misconceptions. Boys exhibited lower levels of knowledge, they also showed a higher tendency to believe in menstrual myths. Girls, in contrast, had better knowledge. The study underscores the importance of integrating boys into menstrual education to reduce stigma and promote gender inclusivity. It suggests that menstrual education should begin before Grade 7 to ensure accurate information is provided before misconceptions take hold. It also calls for teacher training and more open discussions in schools. The research highlights the critical role of health education in challenging menstrual taboos, improving understanding, and fostering empathy across genders, leading to a more inclusive and supportive school environment.

Key words: Health Education, science education, cultural context

Introduction

Menstruation remains a critical area of research, particularly in understanding how education shapes students' knowledge, beliefs, and attitudes. The stigma and misconceptions surrounding menstruation often create barriers to open discussions, reinforcing restrictive social norms. In India, menstruation is frequently associated with cultural taboos that portray it as impure, limiting the participation of menstruating individuals in religious and social activities. While education and media exposure have contributed to changing perceptions, misinformation persists, affecting adolescents' understanding and menstrual health practices. This study explores how middle school students in an urban co-educational school in India understand menstruation and examines whether formal education helps dispel myths and misconceptions.

This study is grounded in Social Constructivism Theory, emphasizing that knowledge is shaped through social interactions, cultural norms, and education. Vygotsky's perspective highlights how family, peers, media, and school influence students' perceptions of menstruation (Akpan et al., 2020). Findings inform curriculum development, teacher training, and gender-inclusive education to challenge misconceptions and foster awareness.

Related literature

Research highlights persistent gaps in menstrual awareness among adolescents. A UNICEF (WaterAid, 2018) study found that 52% of girls in India are unaware of menstruation before menarche, leading to confusion and anxiety. Lack of education contributes to school absenteeism, with 23% of girls dropping out due to stigma and inadequate support (Garg & Anand, 2015). A

review of menstrual health programs in India found that schools with structured education initiatives had lower absenteeism, particularly in model schools with NGO support (Sivakami et al., 2018). In 2014, the Ministry of Health and Family Welfare introduced the National Adolescent Health Programme, called Rashtriya Kishore Swasthya Karyakram (RKSK). This initiative outlined specific guidelines aimed at promoting education, awareness, and improved menstrual hygiene management (MHM) through a peer education approach. The program focused on strengthening protective factors among adolescents to foster resilience, using both community-level and school-based strategies. Although this program aims to address an important issue, we did not find any literature on the actual implementation strategies or on the effectiveness of this programme.

Global research reinforces these findings. In Uganda, students' menstrual knowledge significantly improved after targeted educational interventions, demonstrating the value of structured school-based programs (Kansiime et al., 2020). Studies from Ghana and Afghanistan emphasize the role of sociocultural norms in shaping menstrual beliefs and the importance of including boys in menstrual education to foster a more inclusive learning environment (Mohammed & Larsen-Reindorf, 2020). In India, a cross-sectional study revealed that 76.2% of schoolgirls believed menstruation involved the removal of impure blood, highlighting widespread misconceptions (Seenivasan et al., 2016).

Despite menstruation being part of school curricula, many teachers feel unprepared or uncomfortable discussing the topic (Mukerjee et al., 2023). The success of model schools, which integrate NGO-supported menstrual awareness programs, suggests that structured interventions significantly improve students' understanding and experiences.

Research Questions

This study examines the following:

1. What are the knowledge, beliefs, and attitudes regarding menstruation among 7th and 8th-grade students?
2. What are the sources of this knowledge?
3. How does menstrual knowledge differ between Grade 7 (before formal instruction) and Grade 8 (after formal instruction)?
4. Are there gender-based differences in menstrual knowledge and beliefs?

Research Methodology

This study employed a survey method to examine students' knowledge and beliefs about menstruation. Consent was obtained from the head teacher, and a paper-pencil questionnaire was administered separately to Grade 7 and Grade 8 students. The questionnaire included basic demographic questions followed by 15 menstruation-related questions—one open-ended and 14 multiple-choice or checkbox-based, 3 of these questions were based on the questions used by previous researchers, such as Sakhi et al. (2023). Data was anonymized and analysed using descriptive and inferential statistics.

Study Setting, Participants, And Instructional Context

The study involved 28 Grade 7 students (17 males and 11 females) and 34 Grade 8 students (23 males and 11 females) from a government school in a metropolitan city in India. The school serves underprivileged students, many from migrant families with low parental education. The average age of participants was 12 years (Grade 7) and 13.25 years (Grade 8).

Menstruation-related content at the study site was taught by a female teacher, 48 years old with 11 years of teaching experience. Instruction framed menstruation as a health and rights topic relevant to students of all genders, and the teacher reported encouraging early, curriculum-integrated coverage (e.g., from Grade 5) given earlier pubertal onset and students' exposure to potentially unreliable online information. The topic was introduced through lessons on puberty and adolescence (physical changes, diet/nutrition) and then extended to reproductive development and the menstrual process. Teaching was interactive and used government-authorized materials (e.g., NCERT/SCERT videos), QR-code-linked textbook resources, and project-based student presentations. In the co-ed classroom, the teacher anticipated discomfort (particularly among boys) and addressed it through explicit scientific explanation and structured discussion intended to normalize the topic and support respectful participation.

Findings

This section presents students' knowledge, beliefs, and attitudes regarding menstruation, followed by grade-wise and gender-based differences. The findings are structured around four key themes: comfort level, scientific knowledge, misconceptions and superstitions, and sources of information.

Students' Knowledge, Beliefs And Attitude Regarding Menstruation

Questions Related To Comfort Level

When asked "Do you know about menstruation?", 36% of Grade 7 and 76% of Grade 8 students responded 'Yes', suggesting increased awareness with age and curriculum exposure. 50% of Grade 7 and 15% of Grade 8 said 'A little bit'. 14% of Grade 7 and 9% of Grade 8 students did not know the term.

For "Do you feel embarrassed discussing menstruation?" 25% of Grade 7 and 9% of Grade 8 students said 'Yes', while 50% of Grade 7 and 26% of Grade 8 said 'Sometimes'. 21% of Grade 7 and 62% of Grade 8 students did not feel embarrassed, indicating, although most students did feel embarrassed, there is a decline in stigma with increased age and curricular exposure.

Questions Related To Scientific Knowledge

For "At what age do girls typically start menstruating?", 68% of Grade 7 and 88% of Grade 8 students correctly answered '10-16 years'. The remaining students either underestimated (6-9 years) or overestimated (16-20 years) the age.

For "At what age do women stop menstruating?", 39% of Grade 7 and 59% of Grade 8 students correctly answered '45-55 years', showing lower awareness than that of age of menarche, while the remaining underestimated (30-45 years) or overestimated (after 55 years) menopause age.

Responses for "Which hygiene products have you heard of?" are summarized in Table 1.

Sanitary pads were the most well-known product, likely due to advertisements and availability in general stores. Despite being eco-friendly and traditional, cloth napkins and folded cloth were less recognized.

For an open ended descriptive question, in Grade 7, 4% identified menstruation as a reproductive process, 11% as a periodic process, and 75% lacked scientific understanding. 11% mentioned superstitions such as *"women would be dirty"and "women shouldn't be touched"*.

In Grade 8, 26% identified menstruation as reproductive, 24% recognized it as periodic and 15% mentioned hormones. However, 53% did not understand the shedding of the uterine lining, and 47% lacked knowledge about its periodic nature, indicating gaps despite curriculum exposure.

Table 1: Percentage of students who knew about each of the different hygiene products.

	Sanitary pads	**Folded piece of cloth**	**Menstrual cup**	**Tampons**	**Others**	**Cloth napkin**
Grade 7	96%	11%	14%	11%	0%	0%
Grade 8	68%	15%	12%	15%	21%	9%
Combined	81%	13%	13%	13%	11%	5%

Misconceptions And Superstitions

Students reported commonly held beliefs about menstrual, including:

"Girls cannot go out during menstruation."

"Menstruation should be kept secret."

"Menstrual blood is impure."

In response to "Have you heard of any of the following superstitions?", results are given in Table 2.

Table 2: Percentage of students who are aware of different superstitions.

Superstition	**Grade 7**	**Grade 8**	**Combined**
Menstruating girls should not enter temples or religious places	82%	71%	76%
Menstruating girls should avoid physical activities	43%	47%	45%
Menstruating women and girls should not cook or touch certain food items	39%	47%	44%
Menstruating women and girls should sit separately	36%	44%	40%
Menstrual blood is impure	32%	41%	37%
Menstruation should be kept a secret	36%	35%	35%
We should not touch menstruating women and girls	21%	18%	19%

The belief that menstruating girls should not enter religious places was most widespread. Percentages were similar across grades, suggesting deep-rooted cultural influences.

For "Should dietary restrictions be followed during menstruation?", 46% of Grade 7 and 35% of Grade 8 students said 'Yes', while 43% of Grade 7 and 50% of Grade 8 were unsure.

For "Should girls/women attend school or work during menstruation?", responses were:

25% of Grade 7 and 18% of Grade 8 said 'Yes'.

46% of Grade 7 and 65% of Grade 8 said 'Only if physically fit'

21% of Grade 7 and 15% of Grade 8 said 'No'.

For “Should girls/women participate in physical activities during menstruation?” 36% of Grade 7 and 29% of Grade 8 responded affirmatively, while 44% of Grade 8 said ‘No’, reflecting strong beliefs in activity restrictions.

Differences Between Grade 7 And Grade 8 Students

In addition to qualitative analysis, we also calculated the total scores based on the questions related to knowledge about menstruation. Average score of Grade 8 students (M=63.89%, SD=18.3) was significantly higher than that of Grade 7 students (M=52.98%, SD=21.2) with a moderate effect size ($t(60) = 2.17$, $p = .03$, $d = 0.56$). This indicates that the inclusion of the topic in the textbook and the classroom instruction must have played some role in this improvement.

Table 3: Sources of information about menstruation according to their percentages.

Source	Grade 7	Grade 8	Combined
Teacher	21%	59%	42%
Textbook	4%	62%	35%
Mother	50%	15%	31%
Friends	29%	26%	27%
T.V. advertisement	32%	24%	27%
Internet	39%	9%	23%
A doctor or a health professional	7%	12%	10%
Someone else in the family (sister / grandmother / father etc.) Please specify	11%	3%	6%
Other books (If yes, name the books)	4%	3%	3%
Other sources. Please specify	0%	6%	3%

Sources Of Information

Students’ responses to the question “Where did you get information about menstruation? Tick on all that applies” are given in Table 3.

Teachers and textbooks were the most cited sources for Grade 8, while mothers, TV, and the internet were more common for Grade 7. Few students consulted doctors or health professionals.

For “Would you like to learn more about menstruation?”, 68% of Grade 7 and 59% of Grade 8 said ‘Yes’, while 38% of Grade 8 were uninterested.

For “Should schools play a larger role in menstrual education?”, 54% of Grade 7 and 62% of Grade 8 agreed, though 21% of Grade 8 students opposed it.

For “How would you prefer to learn?” students preferred health professionals (32%), books (29%), and videos (14%), which again suggests unwillingness to discuss the topic in public.

Differences Between Male And Female Students

Table 4 describes the gender-based differences (RQ4).

Table 4: Comparison of Male and Female Students' Knowledge of Menstruation

Category	Girls (%)	Boys (%)
Average Score	71.5% (SD = 15.0)*	52.1% (SD = 19.6)
Awareness of Menstruation	83%	43%
Correct Age of Menstruation	66.7%	33.3%
Correct Age of Menopause	61.1%	44.4%
Primary Source of Information	Mother (55%)	Internet (27%), Friends (28%)
Textbooks as a Source	23%	43%
Teacher as a Source	41%	43%
Friends as a Source	27%	28%
Doctors/Health Professionals	14%	8%
TV Advertisements	23%	30%
Correct Scientific Explanation	10-15%	10-15%
Belief in Myths	1%	25%
No Response on Scientific Info	8%	43%
Alternative Misconceptions	-	"Hormonal imbalance," "Puberty is menstruation"
Embarrassment in Discussing Menstruation	14%	18%
Belief in Dietary Restrictions	50%	35%

* An independent sample t-test revealed that the average score of girls (combining Grades 7 and 8) was significantly higher than that of boys ($t(60) = 4.36$, $p < 0.00$).

Conclusions

The findings indicate a significant improvement in students' understanding of and beliefs about menstruation following formal instruction in Grade 8, compared to Grade 7 students who had not yet covered the topic of reproduction. However, while students demonstrate a foundational awareness, significant lacunae remain in their scientific understanding of the menstrual cycle. Consequently, even after formal instruction, menstrual myths and misconceptions remain prevalent.

A pronounced gender gap was also evident; male students demonstrated significantly lower levels of awareness and understanding compared to their female peers. While female students provided more accurate and informed responses, both genders remained influenced by social taboos and expressed feelings of embarrassment, often subscribing to entrenched myths and superstitions. Although both boys and girls relied on informal sources of information such as mothers for girls

and internet and friends for boys, textbooks and teachers remain a prominent source of information for both genders.

Recommendations

This study demonstrates the necessity for early and comprehensive menstrual health education (MHE). Within the diverse educational landscape of India, levels of menstrual literacy vary significantly across cultural, social, and geographical contexts. Although schools have integrated menstruation into the curriculum, the effectiveness of its implementation remains inconsistent.

Current pedagogical approaches focus predominantly on physiological aspects, often neglecting the psychological and emotional dimensions of the topic. Therefore, a more holistic approach is required to foster a nuanced understanding among students. To enhance menstrual education in Indian government schools, there is a critical need for a curriculum that integrates biological facts with emotional well-being and gender sensitivity.

The study also indicates that textbook-based instruction is insufficient to dismantle long-standing misconceptions and deep-seated social attitudes. To address this, educational stakeholders must prioritize robust teacher-training programs and school-based interventions aimed at promoting menstrual health and hygiene (MHH). Such interventions are particularly vital in schools serving lower socio-economic strata, where misinformation and superstitious beliefs are often more entrenched due to limited educational access.

Furthermore, collaboration between schools, parents, and healthcare professionals is essential to ensure that education is both scientifically accurate and culturally sensitive. Normalizing discussions around menstruation is a prerequisite for fostering an inclusive environment that empowers students to challenge misinformation and advance gender equality.

Directions For Future Research

This study opens several avenues for future inquiry within science and health education. Future research should explore the long-term impact of early-grade menstrual education in mitigating social stigma and taboos. Longitudinal studies, in particular, would be valuable in tracking how students' understanding evolves over time and how formal instruction shapes their long-term perceptions and practices.

Additionally, comparative studies across diverse school settings—including rural, tribal, and private institutions—would provide deeper insight into how socio-economic and cultural variables influence menstrual literacy. Finally, there is a significant gap in literature regarding male students' perceptions of menstruation. Future research should focus on inclusive educational models that involve boys, as gender-segregated approaches often inadvertently perpetuate the very stigma and misconceptions that education seeks to eliminate.

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Section: Health Conceptions In Social Media

EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Exploring Expert Conceptualizations Of Type-2 Diabetes Through Network Analysis: A Pilot Study

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This pilot study explores the conceptual structures of expert knowledge on Type-2 Diabetes (T2D) by applying network analysis to natural language explanations. Ten expert sources including interviews, educational videos, and a reference textbook, were transcribed and transformed into conceptual graphs through an automated pipeline that identifies [concept–relation–concept] triples from sentences. Concepts were categorized into domains of a T2D explanation, and semantic relations were encoded as directed edges. Network analysis techniques, amongst others betweenness centrality and backbone filtering, revealed both consensus and diversity in expert representations. While causes like obesity and family history were widely shared across the sources, treatment strategies lacked convergence. Individual graphs showed variation in node density, thematic foci, and conceptual connectivity. This study demonstrates a novel methodological pipeline for converting unstructured spoken or written expert discourse into analysable knowledge networks. It also suggests that conceptual divergence, even among experts, may influence how T2D is communicated and taught. This approach may extend to other disciplines where understanding conceptualization is crucial for a larger range of applications.

Keywords: Medical Science Education; Conceptualizations; Network Analysis

Introduction

Type-2 Diabetes

Organisms are in constant need for energy to sustain basic functions that include muscle contraction and cell division; for humans, a main source of energy is supplied via ingested food, notably from the glucose contained in carbohydrates. Insulin is a hormone that promotes the absorption of glucose in the blood by the cells of the body, amongst others in the liver and muscles. The latter organs convert the glucose into glycogen or triglycerides, which are forms of energy storage for the body to use. In the pancreas, beta cells are sensitive to the levels of glucose in the blood and promote (to decrease) or inhibit (to increase) insulin production to regulate the blood sugar. Type-2 Diabetes (hereafter T2D) is a chronic disease characterized by the inability of the body to either use insulin properly, or to produce enough of it, leading to high blood sugar levels. People affected by T2D may require regular external doses of insulin, for instance through injection shots, to avoid hyperglycaemic events that can cause potentially serious health complications.

While the pathogenesis of T2D is not fully understood yet, the disease is accepted as a complex multifactorial condition that is influenced by a combination of genetic, metabolic and environmental factors (Goyal et al., 2020). With a doubling of the number of people affected by T2D worldwide over 30 years, from 7% (1990) to 14% (2020) of the population, the condition is linked to over 1 million deaths per year on the planet, making it the 9th leading cause of mortality worldwide (Abdul Basith Khan et al., 2020). Because of the fast spread of the condition to all kinds of populations, T2D research is under important stress to tackle various associated challenges for public and global healthcare. Significant variability still exists in expert conceptualizations of T2D development, consequences, and subsequent medical care (Chatterjee

et al., 2017; Haddad & Haddad, 2018; Nauck et al., 2021). It is therefore critical to establish where the consensus lies with regards to T2D causes, treatment, and prevention.

Medical Science Education

Medical science education responds to the needs to keep the teaching and learning of medical science grounded in the fundamental sciences that compose it, as well as in research-informed best practices (IAMSE, 2026). As such, it has become increasingly multidisciplinary and collaborative, fuelled by an access to digital technologies and greater communication tools, but also because of a need to address rapidly developing complex healthcare challenges (Patel et al., 2005). This context has led to a growing pressure on medical science education to foster better medical reasoning reflected in decision making (Bornstein & Emler, 2001) and problem solving (Groen & Patel, 1985), as well as in the ability to conceptualize the disciplinary fields structuring the medical sciences (Shin, 2019). As academic instruction is provided to students by medical experts with different research profiles, their conceptualizations can influence their teaching contents and methods.

This study investigating the case of T2D within the medical sciences therefore asks the following research question:

What are the common points and differences between expert conceptualizations of T2D?

Revealing and analysing the different modes of knowledge structure and conceptual understanding amongst T2D experts (and, by extension, instructors) could inform teaching and learning in T2D education.

Methodological Frameworks

Conceptualizations And Expertise

Different propositions stemming from the epistemology of science and cognitive sciences have debated how to characterize conceptualizations — also referred to as conceptual understanding — knowledge structures and means to distinguish expertise from less mature stages of experience in a discipline. Amongst these theoretical frameworks, conceptualizations are described as the combination of *content knowledge* and the appropriate judgement on how to *structure* it (Farrington-Darby & Wilson, 2006); the accurate [explanatory/logical/probabilistic] *relations* between *elements in a body of information* (Kvanvig, 2003); the grasp of '*together-hanging*' of *elements in a body of mutually supportive cognitive commitments* (Elgin, 2012); or the patterns of *relations* between *scientific concepts* (Goldwater & Schalk, 2016). A broader discussion on the common points and differences between these propositions is presented by Weihs (2026). All these representations however share a same dual nature, assimilating conceptualization to a set of concepts and the structure that connects them together. Through this lens, expertise is the mode of conceptualization reflected by disciplinary experts, amongst others in their explanation of a topic. Prior research has shown that expert explanations are denser, invoking a higher number of concepts and more relationships between them (Chi et al., 1981).

Network Analysis

The presented dual nature describing conceptualization motivates the use of network analysis as an analytical framework, supported by the suggestion by Siew (2020) that networks can be a plausible representation of knowledge structures. Stemming from mathematical graph theory and applying its algorithmic power in various domains, network analysis characterizes the properties of graph objects, composed of elements/nodes and the relationships/edges between them. Network analysis has recently shown great potential in educational research, revealing relationships between actors, institutions, or concepts in educational contexts, in ways that were

not visible before (Koponen & Mäntylä, 2020). Similarly, network analysis has been successful in studying concept maps used in both teaching and learning settings (de Ries et al., 2022; Kapuza et al., 2020), and recently to investigate scientific explanations (Koponen & Huttunen, 2013; Wagner & Priemer, 2023; Weihs et al., 2025). Particularly, Weihs et al. (2025) developed a methodology to represent and analyse conceptual understanding and knowledge using network analysis, for conceptualizations prompted via scientific explanations contained in concept maps drawn by study participants. In order to operationalize this methodology, one therefore has to have access to conceptual networks capturing the semantics and logics of a scientific explanation; either by collecting concept maps, or by transforming textual explanations into conceptual networks.

Research Design

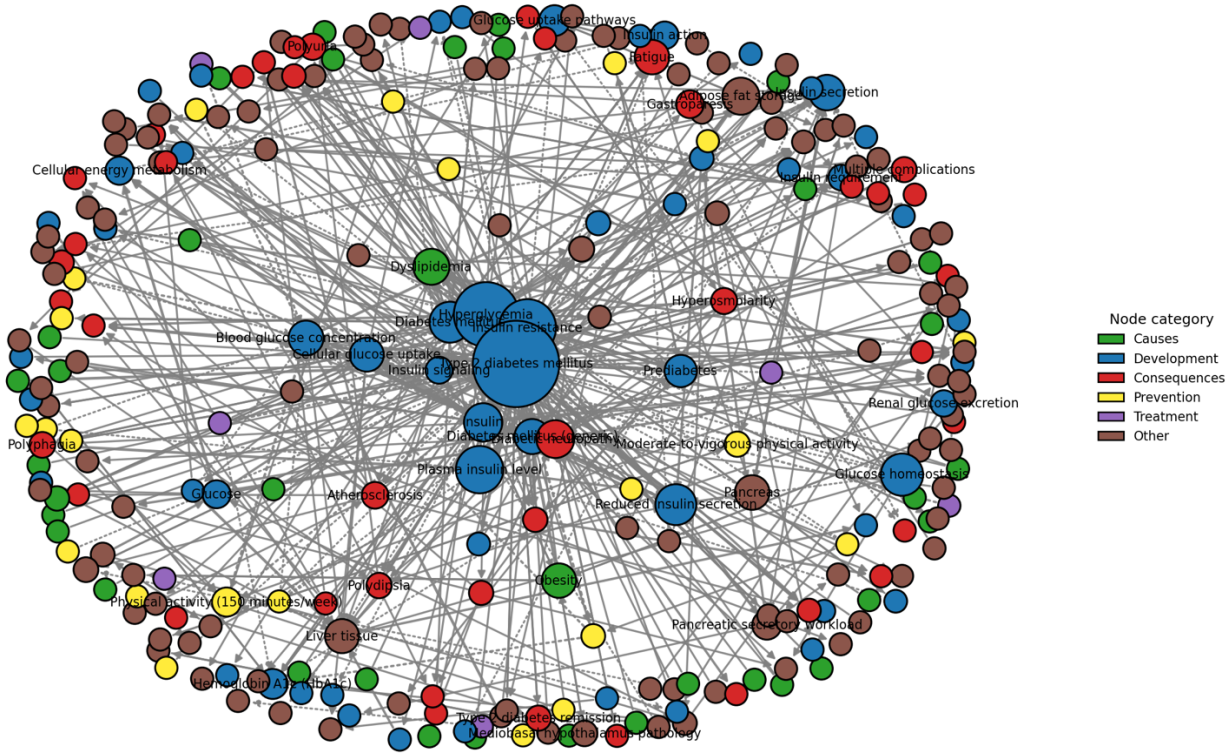
In this study, conceptual networks are created from 10 expert sources on T2D chosen as a convenient sample for their common English language, free accessibility online, and recency: five interviews publicly available on YouTube with the T2D experts Matt Barton from Griffith University, Sarah Hallberg from Indiana University, Vassiliki Bravis from Imperial College Healthcare, Lisa Knust from Riverside Eagle Harbor Primary Care, and Erik Richardson from Ridgeview Family Health; four YouTube educational videos on the topic of T2D by the science education channel *SciShow*, the medical education channel *Understand*, and the diabetes education channels *Animated Diabetes Patient* and *Diabetes UK*; and an excerpt of the fifth chapter 'Epidemiology of Type 2 Diabetes' from a reference textbook on T2D titled 'Textbook of Diabetes' (Holt & Flyvbjerg, 2024). To do so, the nine video sources from YouTube were downloaded as audio files with a script using the *yt-dlp* library, and transcribed with a script using the *whisper* library. Through a Python-coded automated routine using natural language processing tools, the transcripts were then split into individual sentences, and in each sentence, statements with the canonical logic of *[concept A–relation–concept B]* triples were identified. Both concepts in each statement, as well as the relation between them, were coded using inductive thematic analysis (Clarke & Braun, 2017), which informed the creation of an iterative codebook. Each concept was then attributed only one of the six used categories: *Causes*, *Development*, *Consequences*, *Prevention*, *Treatment*, or *Other*. Positive relations such as '*increases*' or '*leads to*' were weighted as 1, while negative relations such as '*decreases*' or '*prevents*' were weighted as -1. For each source, the thematically coded statements were then encoded as nodes connected by a directed edge using the *networkx* library, creating conceptual graph structures for every expert source. These networks were then explored using some tools of network analysis.

Results and Discussions

Joint 'Map Of Type-2 Diabetes'

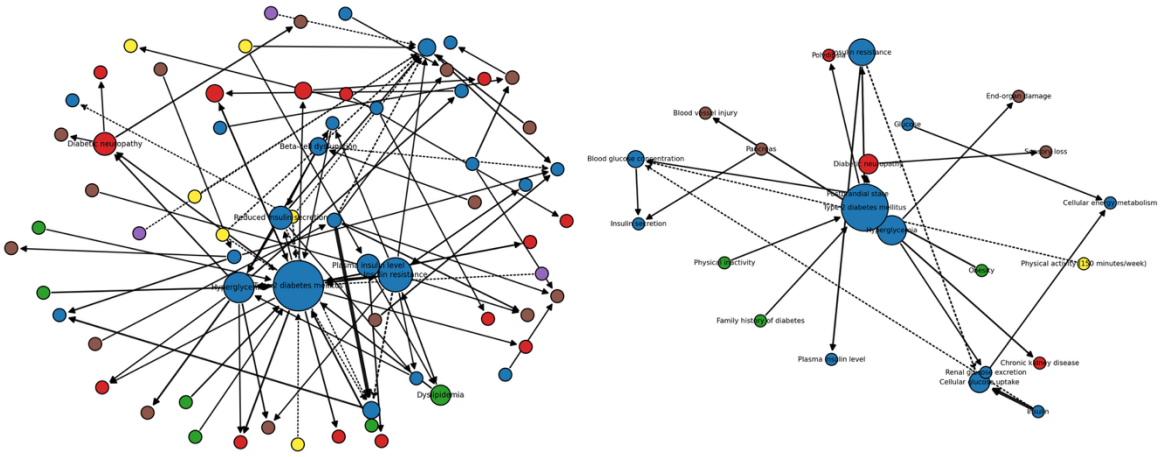
Compiling the information from the networks of all sources yields Figure 1. This joint network presents dense data that can however be regarded as the 'state of current knowledge' about T2D, according to the collected sources. It only shows the labels of the nodes with highest betweenness centrality, in other terms, the nodes most traversed by the paths between any two nodes of the graph network, which can be understood as the most essential concepts that connect the entirety of the knowledge contained in the structure. To improve readability, backbone graphs are created and presented in Figure 2.

Figure 3. Joint network aggregated from all 10 sources. The nodes are colored by category, the node size reflects their betweenness centrality, and the edge style encodes their sign (solid = positive, dotted = negative) with thickness proportional to their number of occurrences across all the sources.



The graph on the left in Figure 2 presents a weight-driven backbone network in which only edges repeated at least twice, even potentially by a same source, are chosen as a filtering criterion. In the right-hand graph, a consensus on edges mentioned by at least three sources is chosen as the filtering criterion. In the latter, three causes of T2D stand out: *obesity*, a *family history of diabetes*, and *physical inactivity*. Similarly, the consensual health consequences are *chronic kidney disease*, *diabetic neuropathy*, and *polydipsia* [an abnormally great thirst]. Such convergences in consensus answer the first part of this study's research question on the common points amongst expert conceptualizations of T2D. The only retained prevention method is *150min/week of physical activity*, and no treatment finds consensus on this graph. This could be due to the different foci of each source on the topic of T2D, which is explored in Figure 3.

Figure 2. Backbone networks filtering the joint network from Figure 1. The graphs are networks only displaying edges mentioned at least twice on the joint network (left), or mentioned at least by three sources (right). The encoding is the same as in Figure 1.



Individual Networks

Figure 3 presents the networks of each source separately. Amongst all sources, the textbook excerpt (bottom-right) particularly stands out, due both to its density in nodes and edges and to the variety of categories addressed. By contrast, some sources in the expert and YouTube channel groups focus significantly more on the prevention of the condition (in yellow), while other sources in both groups elaborate more on the consequences of the condition (in red). Likewise, certain sources present very coherent networks where almost all the nodes are interconnected, while others present two or more disjoint subgraphs, revealing a fragmented explanation where the transition from a topic to another could have been made more explicit. By comparing each individual network to the joint graph, it becomes possible to investigate which concepts and relations are unique to each source, as presented in Figure 4.

Figure 3. Individual networks for each source. The top panel presents the five expert sources (annotated with *E*), the bottom panel presents the four YouTube channel sources (*C*) and the textbook excerpt (*T*). The encoding is the same as in Figure 1.

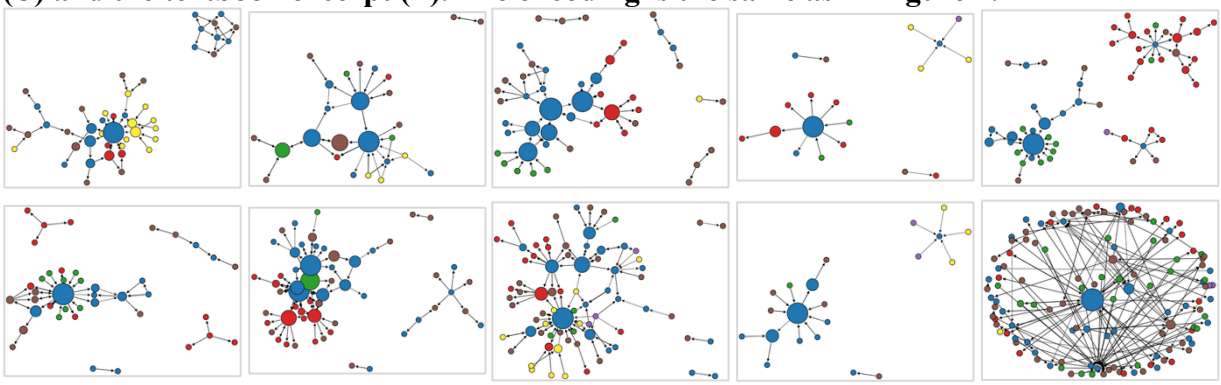


Figure 4. Uniqueness networks filtering the individual networks from Figure 3. The encoding is the same as in Figure 1; the order and annotations the same as in Figure 3.

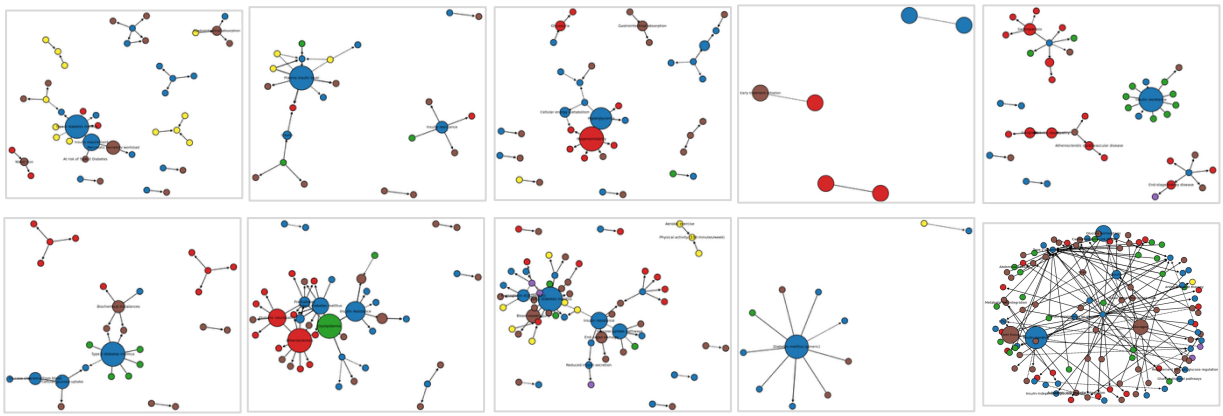


Figure 4 displays the nodes and edges that are specific to each source, and thereby shows what differences exist amongst them, answering this second part of this study's research question on the differences between expert conceptualizations of T2D. The expert source with highest focus on prevention (top-left) mentioned several unique concepts such as *dietary and physical activity monitoring*, *reduced fat, carbohydrate, and sugar intakes*, as well as *stairs climbing* and *more sustained housework and gardening activities* as overall *lifestyle modifications*. Sources focused on the causes (top-right and bottom-left) singularly mentioned *genetic predispositions and membership to high-risk ethnic groups*, but also *abdominal obesity*, *short sleep duration*, *smoking tobacco use* and *older age*, or even possible *medical therapy procedures* as factors elevating the risk of contracting T2D. Interestingly also, treatments are only mentioned exclusively across three sources, which, combined with an absence of consensus for the same category in Figure 2,

indicates possible ongoing debates in the T2D community about the remediation and interventions to cure the disease.

Conclusion

Preliminary Findings

This pilot study has investigated the conceptualizations of 10 expert sources on the topic of T2D, and shown that using automated coding routines enables to convert video into audio, then text, and finally into graph network data. This data can then be explored using network analysis tools, offering a new perspective on the knowledge structures and patterns of conceptual understanding of each source about their discussed topic. Common points as well as differences between sources were identified and helped supporting the idea that currently, there might only exist a partial consensus on the causes, consequences, development, prevention and treatment of T2D. At a time where the disease has become critical for public healthcare worldwide, more research building up on this pilot study could contribute to inform how to best teach the current and next generation of practitioners to most effectively address the global medical challenges associated with T2D.

Limitations

Despite its exploratory nature, this pilot study is subject to several limitations reducing its current scope and explanatory power. First, the small sample situates any claim outside of the realm of statistical significance, rendering the discussions mostly about first order patterns and tendencies. Then, only a triangulation of the used sources with commentary from other T2D experts — or another kind of admitted 'disciplinary truth' — about the results could help validate the findings and ensure that the discussion is grounded in contemporary T2D research, notably by confirming or rejecting statements from the sources. Also, as thematic analysis typically requires measuring an intercoder accuracy score, the analysis performed in this study has not been rigorously verified on a large enough sample to guarantee a maximal level of reliability. Finally, this study assumed that conceptualizations affect how experts teach when becoming educators but did not empirically address how these findings might impact educator training, teaching practices, or learning techniques. These important considerations are left open for follow-up work on the topic.

Implications

Beyond the complementary perspective that this pilot study presents on T2D conceptualization, the methodology it developed and used to convert natural spoken and written language in conceptual networks that capture the semantics and logics of a scientific explanation could have a larger impact on many other types of research. In fact, this method, also discussed amongst others by Wagner (2024), would enable a new type of data collection and subsequent analysis in many human and social sciences. Drawing on the power of network analysis to process this kind of network data could possibly expand the analytical treatment of both previously used and novel types of data sources. In addition, the presented methodology could be extended to the routines of reading and studying scholarly literature, enabling researchers to extract intersections with prior work and identify novel contributions in scientific articles automatically.

Acknowledgement

This research is supported by the Norwegian Centre for Integrated Earth Science Education iEarth (Norwegian Agency for International Cooperation and Quality Enhancement in Higher Education grant #101060).

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