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Modifying Primary School Students' Ideas about Heatwaves in Urban Design Through the "HEATWAVE CITY" Online Game

Maria Christoforaki[1], Nausika Kapsala[1], Manos Skoufoglou[2], Apostolia Galani[2,*]

[1]Department of Pedagogy and Primary Education, National and Kapodistrian University of Athens, Athens, Greece
[2]Department of Pedagogy and Primary Education, National Kapodistrian University of Athens, Athens, Greece
*Corresponding author: ligalani@primedu.uoa.gr

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Abstract This paper highlights the integration of the timely issue of heatwaves into the curriculum through raising empathy, awareness and preparation of youth for the challenge. It will be necessary to examine how primary school students' ideas about managing heatwaves in urban design can be transformed through the "HEATWAVE CITY" online game. Quantitative and qualitative approaches were adopted, and data collection using pre- and post-questionnaires and worksheets (N = 51) aimed to determine students' initial conceptions about managing urban heat waves and assess how such conceptions might be modified after playing the "HEATWAVE CITY" online game. The results of this research illustrate that the online game "HEATWAVE CITY" evidently changes students' perceptions. This active learning environment involved students in problem-solving, decision-making, and exploration in socio-scientific challenges. The manipulative aspect of the approach allowed the students to engage directly with the material, seeing cause-and-effect relationships of their decisions, thus providing depth in their understanding.

Keywords: *Heatwaves, Students' ideas, HEATWAVE CITY online game*

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1. Introduction

It has been fully realized that climate change continues to affect the frequency and severity of natural hazards worldwide [1,2]. In 2020, Europe experienced extreme weather conditions, and heatwaves were ranked the deadliest. According to the European Union 2020, heat waves accounted for 77,637 human lives, about 85 percent of all fatalities associated with natural hazards. This is especially a point of concern in urban areas, where temperatures are usually 3-8°C higher than in rural regions [3]. In Greece, cities such as Athens, Thessaloniki, Rhodes, and Chania experience significant discomfort due to high temperatures combined with elevated aerosol pollution levels and the lack of green spaces [4,5,6]. Furthermore, in 2021, Italy garnered attention when Sicily recorded the highest temperature ever recorded in Europe, and Rome experienced temperatures reaching 40°C at noon. Despite efforts to mitigate the impact of heatwaves, education as a potential solution is not explicitly addressed. UNICEF advocates for the inclusion of education as a vital and cost-effective approach to deal with climate change [7]. Introducing climate change education at an early age helps children develop key competencies that can lead to lifelong sustainable behaviors. As these children become active members of society, the educational benefits extend to entire communities [7]. Nevertheless, education is often neglected as a strategy source to battle against climate change. The complexity of the climate problem, coupled with the lack of solutions that only focus on science and broader socio-economic considerations, are often cited as the main reasons for this oversight [8].

This paper aims to present a critical overview of the impact of the “HEATWAVE CITY” online game on altering students' perceptions of managing urban heatwaves. Therefore, it is of interest to investigate whether students are aware of the prevalence of heatwaves in the urban environment, the associated factors that intensify the Urban Heat Island (UHI) phenomenon, and the mitigation measures and strategies that could be adopted [9]. Thus, our research questions are:

1. What are the primary school students' ideas about addressing heatwaves in urban design?
2. To what extent can the students' ideas about dealing with heatwaves in the urban environment be modified through the “HEATWAVE CITY” online game?

3. How do certain demographic factors (e.g. gender and achievement level) affect primary school students' perceptions about combating urban heatwaves?

The structure of the paper is as follows:

Chapter 1.1 provides a concise overview of heatwaves in urban environments, focusing on the factors influencing their occurrence and intensity, thus establishing the foundational understanding necessary for the subsequent analysis. Building on this, Chapter 1.2 offers a comprehensive description of the online game utilized in the research, detailing its mechanics, functions, and relevance to the study's objectives. The research methodology, including the design, data collection procedures, and analytical techniques, is outlined in Chapter 2, followed by a thorough presentation and analysis of the findings in Chapter 3. Finally, Chapter 4 concludes the paper with a discussion of the findings, emphasizing their broader implications.

1.1. Heatwaves in Urban Environment

Since the Second World War, global urbanization has escalated significantly, with over 52% of the world's population now residing in urban areas—a figure projected to rise to 67% by 2050 [10]. This urbanization leads to the Urban Heat Island (UHI) effect, wherein urban regions experience higher temperatures than their rural counterparts [11]. The global rise in surface and atmospheric temperatures further amplifies the UHI effect, and at the end of the century this will be even more pronounced in cities [1,12]. It is characterized by an increase in frequency, intensity, and length of heatwaves. It can also be defined as periods of extremely high temperature that may persist for a very long time.

Despite the profound impact of heatwaves on society, there is still no universally accepted definition of what constitutes a heatwave [13]. This lack of consensus within the scientific community can primarily be attributed to various geographical factors that affect both the definition and the health impacts experienced by individuals in different regions [14]. According to the World Meteorological Organization [15], a heatwave is defined as a period of five consecutive days during which the daily maximum temperature exceeds the normal maximum temperature by 5 degrees Celsius. These conditions heighten thermal stress for urban populations, leading to higher rates of heat-related mortality and morbidity. Climatic models often overlook the UHI effect, potentially underestimating its health impacts. Exposure to unusually high seasonal temperatures disrupts human homeothermy, raising the risk of illness and preventable deaths even with minor temperature increases.

Therefore, identifying the factors that contribute to the intensification of heatwaves in urban environments is crucial for determining the appropriate mitigation measures. These factors can be categorized as follows [16,17,18,19,20] [21,22,23,24]:

1. Urban Structure and Morphology
2. Rate of Urbanization
3. Urban Surface and Materials
4. Vegetation
5. Climate and Geography
6. Local Structural and Urban Conditions
7. Social and economic factors

The proposed solutions for addressing heatwaves in urban areas are divided into two major categories: (a) measures to address factors that intensify or cause the urban heat island effect, (b) strategies for managing the impacts of urban heat islands. The latter category emphasizes crisis management rather than urban studies. Despite the findings and conclusions that have emerged [25] research on the characteristics of the urban environment related to heatwaves and potential solutions often lacks a holistic perspective. Various factors are examined in isolation, with limited effort to combine or compare their effects, making it difficult to assess the significance of different parameters.

The need for a new approach to address climate change in schools has been identified by many international authorities, including UNICEF, UNESCO, and the European Union [26]. The European Union notes systematic studies for new competencies, skills and knowledge to fight climate change [27]. Although there is a consensus on increasing national and international awareness and commitment to reducing the impact of climate change, UNESCO reports that very few countries are paying specific attention to skills development through education in their national adaptation plans [7]. Some of the most emphasized reasons for this inaction are argued as the complexity and the scale of climate change and the lack of solutions which prefer to only focus on the natural sciences aspect rather than wider socio-economic processes [8].

To address these challenges, the European Union commissioned a systematic literature review that encompasses the most influential educational frameworks on climate change education [27]. Additionally, UNESCO researchers presented a different rationale for climate change education in the context of Sustainable Development [7]. The potential of distance learning practices in the frame of climate change education has been dealt with in a book in 2018 [28].

As derived from a literature review regarding teaching of climate change and heatwaves [29], one of the most effective teaching practices is the use of digitalization techniques, including gamification and serious games [30]. Gamification of learning makes it more fun, interactive, and accessible, with deepened engagement levels. Simulation in education could be considered an educational approach in which learners are put into an environment that provides them with the opportunity to act together with the purpose of solving a problem and testing their knowledge and skills. Serious games can provide an interactive awareness channel for the urban heat island effect through simulation and engaging users, while they may allow creating proactive measures related to urban resilience.

1.2. Serious Game "HEATWAVE CITY"

In constructing a serious game related to heatwave mitigation, the following generic risk factors that provoke misconceptions could be encompassed [31]. The latter would be based on factors like oversimplification of impacts, arbitrary quantifications, incorrect estimation of

the relative weight of single factors, neglecting the effect of a change in some environmental factor upon other urban parameters, and risk of underestimation or overestimation of the contribution coming from climate change. The above observations, coupled with the theory and experience for developing digital educational games - serious games [32,33], allow for the summarization of some critical features with respect to the proper educational functioning of a game related to urban heatwaves. Beyond the standard features of an online game, such as concise and explicit rules, clear user experience and engagement, appropriate graphics, the urban heatwaves game will comprise understandable goals, the availability of altering parameters, the examination of combined factors, a critical grasping of each factor's total consequence in the city, and properly grasped processes of urban development [32].

(https://platform.heatwaves-project.eu/resources/online_game/6)

Figure 1. The "HEATWAVE CITY" online serious game

The primary objective of the game is to combat heatwaves in various areas of the "HEATWAVE CITY" through four distinct missions. In each mission, students are tasked with making appropriate decisions to shape the city, enabling them to identify factors contributing to the intensification of heatwaves and to explore potential solutions. A common goal across all missions is to earn four stars by maintaining the city's temperature at approximately 25°C, ensuring it remains sustainable for all residents. The missions included in the game, corresponding to the factors they examine, are presented in Table 1.

Table 1. Description of "HEATWAVE CITY" serious game stages

Game Missions	Factors Examined
Mission 1 (Concrete Jungle)	Buildings Density
	Height of the buildings
	Rate of Urbanization
Mission 2 (Change the roofs change the city)	Urban structure materials
Mission 3 (Hot pavements)	Urban surface materials
Mission 4 (Park Oasis)	Vegetation and Open Water Sources

2. Materials and Methods

2.1. Sample

The study's target population comprised 5th-grade primary school students (N=51) from a Greek elementary school. The sample included 22 boys, 16 of whom had attained an educational level of A, and 6 an educational level of B. Additionally, there were 29 girls, 17 of whom had achieved an educational level of A, 9 an educational level of B, and 3 an educational level of C, as detailed in Table 2.

Table 2. Description of the research's sample

Academic Achievement Level					
		A	B	C	Total
Gender	Male	16	6	0	22
	Female	17	9	3	29
Total		33	15	3	51

The sample was selected using convenience sampling, as one of the researchers was employed as a teacher at the school where the research was conducted. Parental consent was obtained for the students' participation in the study.

2.2. Tools

We followed a mixed-methods research approach, utilizing both quantitative and qualitative research tools. The first tool was a pre- and post-questionnaire designed to capture primary school students' ideas of addressing heatwaves in urban cities. The items were developed by reviewing relevant literature [34]. It consisted of ten items: two pertaining to the participant's profile (gender and level of achievement), seven 5-point Likert scale items (ranging from 1 = totally disagree to 5 = totally agree), and one multiple-choice question.

The second tool comprised worksheets that accompanied the online game, containing activities aligned with each stage of the game. These worksheets were based on an inventory focused on teaching about climate change developed within the framework of the HEAT project [29].

2.3. Stages of the Research

The research was structured into three stages:

1. Pre-research: This phase involved identifying students' initial ideas on addressing heatwaves in the urban environment, through the online questionnaire.
2. Implementation - formative assessment: This phase included the practical implementation of the online game, and the corresponding worksheets tailored to each stage of the game which were used as material to conduct the formative assessment of the students.
3. Post-research: This phase entailed the administration of the follow-up questionnaire to assess the game's impact on altering students' misconceptions and ideas regarding heatwave management in urban settings.

2.4. Analysis of the Data

The analysis of the data collected followed two methodologies:

A) Quantitative Analysis: The data were collected from the pre- and post-questionnaires. To determine whether there was a significant change in the students' pre- and post-questionnaire responses, we

followed a one-way repeated measures analysis of variance (ANOVA). This analysis examined potential interaction effects between:

1. The change between the pre- and post-questionnaire responses
2. Gender
3. Academic Achievement level

B) Qualitative Analysis: The worksheets were analyzed through content analysis, which is useful for in-depth qualitative data evaluation and is helpful for assessing events or processes in a society [35]. The content analysis of the worksheets followed three stages:

1. Identifying activities in the worksheets based on the factors that are examined in each game mission
2. Determining words, phrases or concepts that correspond to each factor examined by the corresponding activities
3. Categorizing students' responses for each factor in each game mission

Based on the above, we created a content analysis rubric for the worksheets as shown in Table 3. Students' responses for each factor were categorized into two groups, as detailed in the results section. The coding was carried out by one independent researcher. The coder was trained using a preliminary subset of approximately 10 worksheets. To avoid any loss of meaning, all worksheets were analyzed in Greek.

Table 3. Content analysis concepts of the worksheets' activities

Worksheet Activities	Factors Examined	Concepts/ Phrases/Words
Concrete Jungle	Buildings Density	**More Buildings** and lead to a temperature **increase** **More buildings** can lead to a **decrease** in temperature The number of buildings is not related to heatwaves
	Height of the buildings	To address heatwaves our buildings should be **taller** To combat heatwaves, our buildings should be **shorter**
	Rate of Urbanization	The population of a city is not **related to heatwaves** **More people** mean an **increase** in temperature
Change the roofs change the city	Urban structure materials	Metal roofs or green roofs absorb **less heat** Tiled roofs absorb less heat
Hot pavements	Urban surface materials	Asphalt roads and grey roads are **responsible for the UHI** Road surface materials are not related to the urban heat island effect
Park Oasis	Vegetation and Open Water Sources	More trees, parks and fountains can decrease temperature

The following example illustrates the analysis of a random student's response to one of the activities included in the worksheets:

Worksheet Activity: *"According to recent developments on the Ukrainian front, 400 Ukrainian citizens have arrived in your country as refugees. Greece, as a host country, is required to provide appropriate welfare measures for their accommodation and has decided that these people will be settled in this city. As urban planners and members of the city council, it is evident that new housing facilities need to be created. You are therefore asked to decide on the one hand, the locations where the new buildings could be placed without intensifying heatwaves in your city, and on the other hand, to consider how the height of the new buildings might contribute to the worsening of heatwaves.*

How do you think building height affects temperature? Justify your answer".

Student's response:

"I believe that the new buildings that need to be constructed to accommodate the refugees in our city should not be too tall. The taller a building is, the quicker it is exposed to the sun's rays, meaning it will not stay cool during the day and will have higher temperatures".

By analyzing the student's answer, we identify the key phrases "*should not be too tall*" and "*higher temperatures*", concluding that the student suggests shorter buildings as a solution to heatwaves.

The research study fully adheres to ethical guidelines. Since the sample consists of primary school students, special permission was obtained from the parents and guardians. They were informed about the purpose and scope of the study, allowing them to decide whether they wished for their children to participate in the research.

3. Results

3.1. Investigating the Primary School Students' Perceptions on Addressing Heatwaves in Urban Design

The primary school students' ideas about addressing heatwaves in urban design were examined through a pre-research questionnaire. An analysis of the distribution of the pre-questionnaire responses from Greek primary school students in the 5th grade, as presented in Table 4, reveals several noteworthy findings. A significant number of the students, 21 out of 51, hold the misconception that to deal with heatwaves, the windows and doors of the houses should be kept open at midday on hot days. Furthermore, Table 4 shows that 17 out of 51 students do not recognize that heatwaves cannot affect cities across Europe in a similar manner. However, it is important to underline that 17 students seem to disagree with the notion that heatwaves do not affect Europe differently from other regions, while 18 students almost agree with this statement, reflecting a divided understanding among them.

On the other hand, 24 students believe that utilizing vegetation, such as creating green corridors and forests, can effectively mitigate heatwaves. This aligns with contemporary urban planning strategies that emphasize the importance of green infrastructure in enhancing urban resilience to climate change. Similarly, 20 students almost agree that outdoor sprinklers and fans can contribute to alleviating the effects of heatwaves.

Moreover, the majority of the students recognize that making cities resilient to heatwaves requires a

multifaceted approach. They believe that the key strategies involve a combination of passive cooling techniques, reducing buildings' energy consumption, and redesigning urban areas with more vegetation and open spaces.

3.2. To What Extent Can the Students' Ideas About Dealing with Heatwaves in the Urban Environment Be Modified Through the "HEATWAVE CITY" Game?

Testing the modification of students' ideas about how to deal with heatwaves in the urban environment through the online game "HEATWAVE CITY" was conducted in two stages: (a) formative assessment (worksheets) and (b) post-test (questionnaires).

3.2.1. Remarks on Formative Assessment

A further look at students' answers to the worksheets (Table 5) used as formative assessment, after they finished the "HEATWAVE CITY" online game, reveals several key insights. Notably, 20 out of 51 students did not recognize the relationship between building density and urban temperature, nor the fact that increased density can contribute to elevated heat levels. While the majority of students advocated for shorter buildings as a measure to address heatwaves, 38 students held the misconception that the population of a city is not related to heatwaves. This misconception aligns with the misconception recognized in the questionnaire regarding the way European cities are affected by heatwaves, compared to other regions, and the idea that heatwaves can affect cities the same way across Europe.

In terms of urban surface and structure materials, 39 students agreed that metal (19 students) and green (20 students) roofs absorb less heat than adobe or porous materials. Additionally, 37 out of 51 students correctly identified that street materials such as asphalt used in street construction can exacerbate the urban heat island effect.

Table 4. Primary school students' answers to the pre- questionnaire regarding their knowledge about addressing heatwaves in urban environments

Items	Strongly Disagree	Disagree	Almost agree	Agree	Strongly Agree
Q1.Outdoor sprinklers and fans can contribute to reducing urban temperatures	11	10	20	6	4
Q2.Creating forests within cities and green corridors is an effective way to shift airmass to cool large areas within a city	2	7	24	8	10
Q3.Windows and doors should be kept open at midday on hot days as a strategy to face heatwaves	9	2	19	11	10
Q4.Heatwaves can exacerbate the urban heat island effect in European cities	3	5	30	9	4
Q5.Heatwaves affect cities the same way across Europe	12	7	17	12	3
Q6.Heatwaves do not affect European cities differently from other regions	8	17	18	5	3

* Since the research sample is modest, the results are presented in absolute numbers

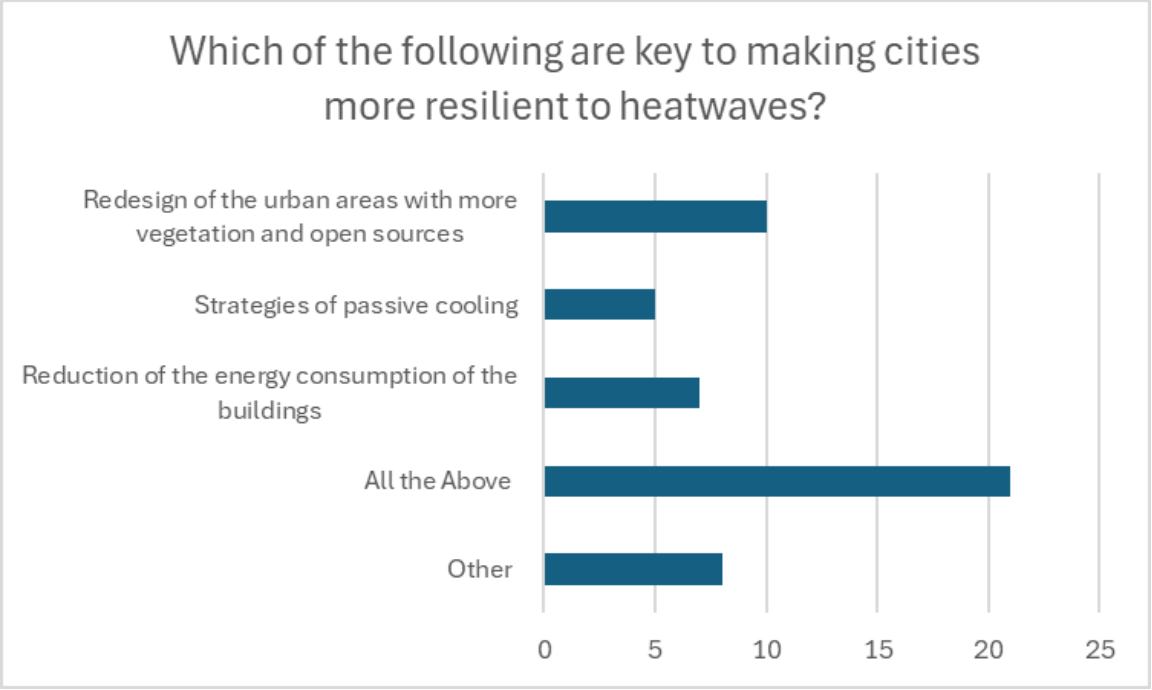

Figure 1. Primary school students' answers to the question, "Which of the following are key to making cities more resilient to heatwaves?" (pre-questionnaire).

Table 5. Formative assessment results of worksheets' activities

Factor	Perceptions	Students' Responses
Building Density	More buildings lead to an increase in temperature	13
	More buildings can lead to a decrease in temperature	20
	The number of buildings is not related to heatwaves	18
Height of the buildings	To cope with heatwaves, our buildings should be taller	11
	To cope with heatwaves, our buildings should be shorter	40
Rate of urbanization	The population of a city is not related to heatwaves	38
	More people mean an increase in temperature	13
Urban Structure Materials	Metal roofs and green roofs absorb less heat	39
	Tile roofs absorb less heat	12
Urban Surface Materials	Asphalt roads and gray roads contribute to the urban heat island effect	37
	The materials of road surfaces are not related to the urban heat island effect	14

3.2.2. Comparing Answers of the Pre- and -Post Research Questionnaires

A paired sample t-test was conducted to compare the pre-test and post-test scores utilizing Cohen's d and Hedges' g to determine the statistical significance difference and effect size of the intervention (Table 6). Employing both Cohen's d and Hedges' g allows us to capitalize on the strengths each measure offers: Cohen's d for its widespread use and interpretability in larger samples, and Hedges' g for its adjustment for smaller sample sizes, ensuring a more precise effect size estimation.

The results indicate that the intervention had a statistically significant positive impact. Cohen's d was calculated to be 0.48021, indicating a medium effect size, which suggests that the "HEATWAVE CITY" online game intervention moderately improved students' performance. The confidence interval provides a range from 0.021 to 0.583, which does not include 0, thereby confirming the statistical significance of the effect size at the 95% confidence level.

Similarly, Hedges' g, which provides a slight adjustment for small sample sizes, yielded a value slightly higher than Cohen's d, also indicating a medium effect size. The confidence interval for Hedges' g was nearly identical to that of Cohen's d, ranging from 0.021 to 0.574. This interval also excludes 0, reaffirming the statistical significance of the effect size [36].

These findings suggest that the implementation of the online game is effective in altering students' ideas about confronting heatwaves in urban environments and could be considered for broader implementation to enhance student learning outcomes in environmental education.

In particular, the distribution of the students' responses to the post-questionnaire confirms the findings discussed above (Table 7). Notably, while 21 students initially believed that windows and doors open at midday on hot days, after the intervention, 18 students totally disagreed with this statement. Another significant shift was observed in students' recognition of the regional variability of heatwave impacts: 23 out of 51 students' post-intervention acknowledged that heatwaves could affect European cities differently compared to other regions (i.e., Southern Europe experiencing more intense heatwaves than Northern Europe), a concept that was highlighted in both the pre-intervention questionnaire and the worksheets.

The majority of the students of our sample consistently supported the creation of green corridors with forests and parks, as well as the use of outdoor sprinklers and fans, even after engaging with the online game.

Remarkably, the number of students who endorsed the idea that making cities resilient to heatwaves, requires a combination of passive cooling strategies, reducing buildings' energy consumption, and redesigning urban areas to incorporate more vegetation and open spaces, was increased from 21 students to 28.

Table 6. Effect Sizes for Paired Samples: Pre- and Post-Intervention Score Comparison

		Standardize	Point Estimate	95% Confidence Interval	
				Lower	Upper
PRE SCORE	Cohen's d	0.48021	0.303	0.021	0.583
POST SCORE	Hedges' g correction	0.48757	0.299	0.021	0.574

Table 7. Primary school students' answers to the pre- and post-questionnaire regarding their knowledge about addressing heatwaves in urban environments

*Items	Strongly Disagree		Disagree		Almost Agree		Agree		Strongly Agree	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Q1	11	9	10	11	20	20	6	8	4	3
Q2	2	3	7	4	24	18	8	15	10	11
Q3	9	18	2	14	19	7	11	8	10	4
Q4	3	2	5	3	30	16	9	27	4	3
Q5	12	9	7	22	17	15	12	5	3	0
Q6	8	12	17	23	18	13	5	2	3	1

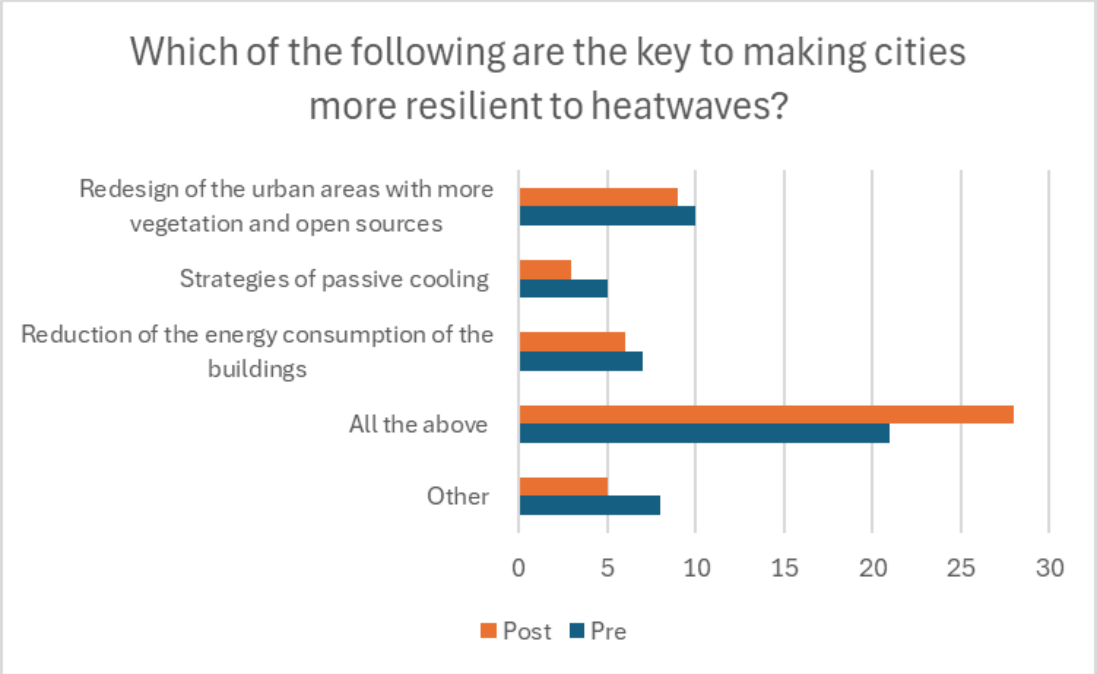

Figure 2. Primary school students' answers to the question, "Which of the following are key to making cities more resilient to heatwaves?" (pre- and post-questionnaire comparison)

3.3. Correlation of the Heatwaves to the Demographic Variables

Tests of between-subjects effects were conducted to assess the impact of demographic variables on both pre- and post-research such as gender and academic achievement level, on students' general knowledge about dealing with urban heatwaves (Table 8).

Table 8. Tests of Between-Subjects Effects for Demographic Variables

Dependent Variable: Pre_Score					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.638[a]	4	0.159	1.048	0.393
Gender	0.335	1	0.335	2.201	0.145
Academic Achievement Level	0.217	2	0.109	0.714	0.495
Gender * Academic Achievement Level	0.023	1	0.023	0.151	0.700
Corrected Total	7.633	50			
a. R Squared = .084 (Adjusted R Squared = .004)					
Dependent Variable: Post_Score					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.390[a]	4	0.098	0.798	0.533
Gender	0.201	1	0.201	1.645	0.206
Academic Achievement Level	0.070	2	0.035	0.285	0.753
Gender * Academic Achievement Level	0.310	1	0.310	2.533	0.118
Corrected Total	6.015	50			
a. R Squared = .065 (Adjusted R Squared = -.016)					

For the pre-test scores, the corrected model accounted for a Type III Sum of Squares of 0.390 with 4 degrees of freedom, resulting in an F-value of 0.798 and a p-value of 0.533. In both cases the p-values exceed the 0.05 threshold, indicating that the predictor variables do not significantly predict either pre-test or post-test scores.

When examining gender as an individual predictor, the analysis for pre-test scores yielded a Type III Sum of Squares of 0.335 with a p-value of 0.145. For post-test scores, the Type III Sum of Squares was 0.201 with a p-value of 0.206. In both cases, the p-values exceed the 0.05 threshold, suggesting that gender does not have a statistically significant effect on either pre-test or post-test scores.

Regarding academic achievement level, the pre-test scores resulted in a Type III Sum of Squares of 0.217 with a p-value of 0.495, while the post-test analysis resulted in a Type III Sum of Squares of 0.070 with a p-value of 0.753. These p-values indicate that different levels of academic achievement do not significantly affect scores in either test.

The interaction between gender and academic achievement level was also examined. For pre-test scores, the interaction had a Type III Sum of Squares of 0.023 with a p-value of 0.700, and for post-test scores, a Type III Sum of Squares of 0.310 with a p-value of 0.118. Again, the p-values are greater than 0.05, indicating no significant interaction effect on either pre-test or post-test scores. The R-squared value for the pre-test model was 0.084 (adjusted R-squared = 0.004), while the post-test model had an R-squared value of 0.065 (adjusted R-squared = -0.016). These low values suggest that the models explain only a small proportion of the variance in both pre-test and post-test scores, with the adjusted values indicating almost no explanatory power.

The analysis of between-subjects effects shows that neither gender, academic achievement level, nor the

interaction between them significantly predict pre-test or post-test scores. The overall models explain very little variance in the scores, suggesting that other unexamined factors likely play a more substantial role in influencing student performance. Further research is necessary to identify these factors and to develop more comprehensive models to better understand the determinants of academic success.

4. Discussion

This research aimed to identify potential misconceptions among students regarding confronting urban heatwaves, and to examine the modification of these misconceptions following the intervention of the "HEATWAVE CITY" online game. Given the growing occurrence and severity of heatwaves worldwide, it is imperative to integrate this issue into education through educational curricula, providing students with both accurate scientific information and opportunities to develop key skills of action and decision-making. Although numerous studies have been published on perceptions of climate change, global warming and greenhouse effect, there are limited studies conducted exploring public perceptions of heatwaves and especially the factors contributing to intensifying urban heatwaves and addressing them.

In our research, we examined the ideas of 5th-grade Greek primary school students regarding dealing with heatwaves in urban environment and assessed how these ideas can be modified through the online game. The research was divided into three stages: (a) pre-research, (b) formative assessment (intervention), and (c) post-research.

During the pre-research, most students (21 out of 51) recognized that making cities resilient to heatwaves requires a multifaceted approach. They emphasize the importance of passive cooling techniques, such as natural ventilation and reflective materials, to reduce indoor temperatures without relying on air conditioning. Additionally, they highlight the need to decrease buildings' energy consumption through energy-efficient technologies and renewable energy sources. Students also stress the significance of redesigning urban areas to include more vegetation and open spaces, such as parks and green roofs, which cool the environment through shading and evapotranspiration. This comprehensive understanding reflects current urban planning strategies and underscores the importance of integrating various methods to effectively manage urban heatwaves.

The misconception that population and building density are unrelated to temperature increases contradicts well-established knowledge, which demonstrates that rising population and building density in urban areas are directly linked to increases in temperature [11]. Factors such as Urban Surface and Materials, Vegetation, Climate and Geography, Local Structural and Urban Conditions and Social and economic factors uniquely impact each city, leading to a different way to be affected by heatwaves [16,17,18,19,20] [21,22,23,24]. This indicates a significant gap in understanding the factors contributing to urban heatwaves and the way they should be addressed. This gap often stems from a lack of knowledge about heatwaves, as there is ineffective education and communication about the issue [37]. Effective education and communication are crucial to bridging this gap, ensuring that individuals and communities are better informed about the causes and impacts of heatwaves.

Research has recognized that utilizing passive cooling, reducing energy consumption, vegetation, and open water sources can eliminate the urban heat island effect [19,22]. This was also confirmed by students' responses during the pre-research to both the questionnaire and the worksheets, as they supported that making cities resilient to urban heatwaves, the key strategy is a combination of passive cooling, reduction of buildings' energy consumption and redesign of urban areas with more vegetation and open sources.

Given the responses collected during the post-research, it is challenging that after the intervention through the "HEATWAVE CITY" online game, misconceptions of the students were modified. Most students (18 out of 51) totally disagreed with the fact that we should keep windows and doors open at midday on hot days, while 23 now believe that heatwaves can impact European cities differently compared to other regions. Also, after participating in the online game, the majority of students (26 out of 51) remained strongly in favor of establishing green corridors with forests and parks, as well as using outdoor sprinklers and fans.

By employing the "HEATWAVE CITY" game we foster an interactive learning environment wherein students actively engage in problem-solving, decision-making, and exploration of complex socio-scientific challenges associated with addressing heatwaves in the urban environment. This hands-on approach enabled students to directly interact with the material and observe the consequences of their choices, facilitating a more profound comprehension of the subject matter. Additionally, the game encouraged collaboration and critical thinking, as students worked together to devise and implement strategies to mitigate the effects of heatwaves. By simulating real-world scenarios, the game helped bridge the gap between theoretical knowledge and practical application, empowering students to better understand the multifaceted nature of urban heatwave management and the importance of sustainable urban planning. This experiential learning method not only increased their knowledge but also inspired a sense of responsibility and proactive attitude towards addressing climate-related issues. Recent research underscores the effectiveness of gamification in climate education, highlighting its potential to enhance learning outcomes and engagement. A study demonstrated that incorporating game elements into educational activities significantly boosts students' motivation and understanding of complex subjects, such as climate change [38]. Furthermore, gamified learning experiences have been shown to support knowledge retention and application by transforming abstract concepts into tangible experiences [39].

In the context of climate education, games like "HEATWAVE CITY" provide a dynamic platform for students to explore the multifaceted nature of climate challenges, especially heatwaves and the interconnectedness of various mitigation strategies. For instance, through the game, students can experiment with creating green corridors and reducing energy consumption to observe their collective impact on urban heat

management. This experiential learning fosters a deeper understanding of how individual and collective actions contribute to climate resilience. Additionally, the collaborative nature of such games encourages teamwork and critical thinking, as students work together to devise and implement effective strategies.

The integration of gamification in climate education not only enhances cognitive learning but also instills a sense of agency and responsibility in students. By simulating real-world scenarios, games help bridge the gap between theoretical knowledge and practical application, empowering students to take informed actions in their communities. Well-designed educational games could provide immersive, context-rich environments that promote active learning and long-term engagement with critical issues like climate change [40].

Regarding the demographic factors, neither gender nor academic achievement level presented a significant correlation to the results either to pre- or post-research results. This suggests that the effectiveness of the "HEATWAVE CITY" game as an educational tool transcends these variables, making it broadly applicable across diverse student populations. The absence of significant differences based on gender and academic achievement underscores the game's potential to engage and educate a wide range of learners equally. Inclusivity is particularly important in climate education, where understanding and addressing climate change requires collective action across all segments of society. By providing an equitable learning platform, gamification ensures that all students, regardless of their background, can develop critical thinking skills and gain a comprehensive understanding of climate issues. This is aligned with research, which found that well-designed games can level the playing field by providing diverse learners with equal opportunities to succeed and learn [41]. Moreover, the universal appeal of the "HEATWAVE CITY" game highlights its potential as a scalable educational tool that can be implemented in various educational settings, from urban to rural schools, and across different cultural contexts. This scalability is crucial for widespread climate literacy, as it enables the dissemination of effective climate education strategies on a global scale. The use of gamification in climate education, exemplified by the "HEATWAVE CITY" game, proves to be an effective and inclusive strategy. It not only enhances students' understanding and engagement but also ensures that climate education is accessible and impactful for a diverse range of learners.

5. Limitations

One potential limitation is the proximity of the researcher to the participants during the process of familiarizing them with the concept of heatwaves in the urban environment, as well as during the implementation of the study. A criticism often directed at the participatory role of the researcher in the research process concerns the potential bias that may arise due to this proximity [36,42]. However, data triangulation contributed to capturing the students' genuine perceptions regarding heatwaves in the urban environment. Another limitation is the duration of the research. Conducting the study over a longer period for each stage (pre-research, intervention, post-intervention) could have ensured more representative results. Finally, a potential limitation is the sample size of the students. Implementing the present study with a larger sample of primary education students could have revealed a greater improvement or modification in their ideas regarding urban environment design to address heatwaves, following the intervention with the digital game "HEATWAVE CITY".

6. Conclusions

In conclusion, this research highlights the importance of addressing misconceptions among students regarding urban heatwaves and demonstrates the potential of the "HEATWAVE CITY" online game as an effective educational tool. The study revealed that while students initially possessed a sound understanding of some urban heatwave mitigation strategies, there were critical gaps in their knowledge, particularly regarding the relationship between population density and temperature increases, as well as the differentiated impact of heatwaves across European cities. However, the post-research results indicate that the interactive and experiential learning environment fostered by the game successfully modified some of these misconceptions.

The gamified approach not only increased students' knowledge but also cultivated essential problem-solving and decision-making skills, providing them with a more profound understanding of urban heatwave management. The collaborative nature of the game further promoted teamwork, aligning with recent research that underscores the value of gamification in enhancing climate education. Importantly, the study also found that the effectiveness of the "HEATWAVE CITY" game transcended demographic variables such as gender and academic achievement, making it an inclusive educational tool for diverse student populations.

Ultimately, this research underscores the need to integrate climate issues like heatwaves into education, using innovative tools such as gamification to bridge the gap between theoretical knowledge and practical application. By empowering students to actively engage with complex environmental challenges, we can foster a generation equipped with the knowledge and skills necessary to build climate-resilient communities.

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Statement of Competing Interests

No new data was created in this study. The data that support the findings of this study are not publicly available due to privacy and/or ethical restrictions. Access

to the data is restricted to protect the confidentiality and privacy of the participants. For further inquiries, please contact the corresponding author. The authors declare no conflict of interest.

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