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Climate Change Education through Earth Observation: An Approach for EO Newcomers in Schools

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Abstract: Earth Observation (EO) is widely recognized as a powerful tool for Climate Change and Sustainability Education (CCSE); however, the uptake of EO data in schools is still limited due to technical, motivational, or informational barriers. A major factor for the exploitation of EO in schools is the availability of curriculum-relevant pedagogical content that is attractive and personally meaningful to learners. Here, we examine whether an EO-based learning scenario developed for primary schools and implemented by EO novice teachers and students, based solely on written instructions, can serve as an effective entry point for incorporating EO into schools and addressing CCSE objectives. Our study showed that: (a) cloud-based EO tools are suitable for EO-novice teachers and students, who quickly become familiar with them and grasp basic EO concepts; (b) the combined use of EO-based and place-based learning helps students bridge the local and the global perspective of Climate Change (CC) impacts; (c) EO-based educational material stimulates students' interest for satellites and EO technology; (d) the phenomenon-based approach grabs students' attention, provokes their curiosity, and acts as a springboard for scientific inquiry on CC impacts; and (e) our scenario's learning approaches promoted teachers' upskilling and intra-school collaboration.

Keywords: Earth Observation; Climate Change and Sustainability Education; phenomenon-based learning; place-based learning; EO browser; primary school

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1. Introduction

New research on climate tipping points [1] reinforces the view that Climate Change (CC) and environmental degradation pose an existential threat to the world, which urgently needs to take the necessary actions for sustainable development and CC adaptation and mitigation.

In this context, the international community agrees that sensitization of young people for the anticipated climate crisis needs to start in schools, which are the primary platform for equipping the upcoming generation of citizens for the challenges that lie ahead. The United Nations Framework Convention on Climate Change [2], the Paris Agreement [3], and the European Green Deal [4] all consider schools as places to engage pupils on the changes needed to address the urgent climate challenges. In response, the European Commission launched in 2021, in collaboration with UNESCO, the Education for Climate Coalition initiative [5], aiming to mobilize the education community towards a true bottom-up Climate Change Education (CCE) engagement. UNESCO has been advocating for years on the critical role of CCE in K–12 settings as a means of empowering people with the knowledge, skills, values, and attitudes necessary to mitigate and adapt to the impacts of climate change. In its capacity, UNESCO considers CCE essential for preparing societies to address the climate crisis. It argues that by helping young people to understand the causes and consequences of climate change, they are more likely to take action to reduce their own carbon footprint and to support future policies and initiatives that contribute to a more sustainable future [6–10]. Research also suggests that climate change-related programmes at school influence not only the students', but also their parents' views on the subject by increasing parents' level of concern, adopting more eco-friendly lifestyles, and erasing some ideological rifts about climate change.

It is, therefore, encouraging that Climate Change and Sustainability Education (CCSE) is increasingly taking center stage in school curricula across the world and is not considered a peripheral issue for educational systems any more [10]. To further enhance CCSE objectives, educators and policy makers are continually seeking new ways, innovative approaches, and tools for promoting climate literacy and sustainability goals among learners.

Due to its inherit interdisciplinary nature, Earth Observation (EO) is widely recognized as one such powerful approach that can benefit climate change education, besides advancing students' technical and scientific literacy and skills [11–17]. EO data can help today's learners and tomorrow's citizens build a sustainable future and a resilient society, as it delivers unique insights of numerous environmental processes with a high degree of vividness through its open, consistent, verifiable, and granular data to anyone, anywhere in the world. EO enables learners to focus on local CC impacts and, thus, makes CC personally relevant and meaningful. It also enables them to interact with authentic scientific data for studying changes on Earth's surface, taking place at multiple temporal and spatial scales. Meanwhile, as emerging technologies are revolutionizing the use of EO, teachers and students have the opportunity to engage with cutting-edge scientific discovery and technological innovation and, thus, benefit tremendously from this new epoch of space data, e.g., [18] and references therein.

Over the last few decades, there have been many efforts by universities, institutions, and space agencies to promote EO in schools and harvest its pedagogical benefits, e.g., [19]. As a result, a variety of relevant learning environments, applications, websites, pedagogical material, and projects have been developed and offered to teachers and students. Some European examples include:

- Remote Sensing in Schools (FIS), an online learning environment and teaching materials by the Ruhr-University of Bochum [16,20];
- Erasmus+ projects such as EO4Edu [21] and GIS4Schools [22] that exploit EO in order to address the impacts of climate change;
- Columbus Eye project by the universities of Bochum and Bonn, which brings the ISS closer to teachers and students through live and archived images and smart-phone Artificial Intelligence Applications [23,24];
- Geo:spektiv, an e-learning platform that promotes the integration of EO into the school curricula through environmental- and space-relevant topics [14];
- Eduspace, ESA's website that encourages teachers to use EO data by providing ready-made didactical material [25];
- Climate Detectives, ESA's schools project initiative that encourages schools to investigate Earth's climate based on EO data [26];
- EO-based classroom resources developed by the various European Space Education Resource Offices (ESEROs) in cooperation with national partners.

However, exploitation of EO in European schools is still limited mainly due to technical, motivational, or informational barriers alongside significant language barriers as most learning materials and applications are usually available in a limited number of languages [15,16,18,27,28]. For compulsory education to capitalize on EO, teachers need suitable preconditions, i.e., user-friendliness, reduced-complexity, and intuitive EO-based applications and learning materials, that require minimum-to-no training, minimum IT infrastructure requirements, and little lesson preparation time alongside a pedagogical content with curricular relevance that is based on real-life scenarios and well-established teaching and learning approaches [17,18,28,29].

As for Greece, the country where we focus our study, in addition to these barriers, there is also an unfavorable school curriculum that does not provide the necessary framework for EO utilization due to lack of relevant references in the topics taught, lack of suggestions or instructions to teachers, and limited use of satellite imagery in textbooks, which are used as mere iconographic elements (see [25,30]). However, recent developments in Greece, such as the ones described below, created improved conditions for incorporating EO-based educational activities into Greek schools, specifically:

- The establishment of the Greek ESERO branch [31] in November 2021, marked the commencement of a countrywide initiative aimed at fostering the integration of space-related educational programmes within Greek schools. ESERO Greece seeks to foster interest in space science and technology, enhance STEM literacy and skills, and support the UN's Sustainable Development Goals by translating ESA's educational activities, promoting Greek teachers' participation in space-related training programmes, and facilitating Greek schools' involvement in ESA competitions.
- The 2021 reform of the school curriculum by the Greek Ministry of Education introduced a new curricular subject in the weekly school programme, called "Skills Laboratories" (See Appendix A). This new subject was designed for enabling the implementation of extended, interdisciplinary, and collaborative educational activities in specific thematic areas, such as environmental sustainability, health and well-being, robotics, entrepreneurship, and more. On average, one didactic hour per week was allocated for Skills Laboratories in the students' school timetable, and each selected topic was anticipated to be addressed over a duration of two months.
- The initiatives that researchers at the Operational Unit "BEYOND Center for EO Research and Satellite Remote Sensing" of IAASARS/NOA have taken for fostering EO awareness and utilization in compulsory education. Specifically, BEYOND developed the "BEYONDedu: Educational Programme on Space Technology and Remote Sensing", aiming to introduce primary and secondary school students and teachers to the technological world of satellite remote sensing. Since 2021, more than 2000 students have participated in the BEYONDedu activities held in schools across Greece. Furthermore, BEYOND, in collaboration with the Centre of Excellence ERATOSTHENES in Cyprus, has been implementing the ERASMUS+ project "Space EDUnity", which encourages student communities to use crowdsourced in situ and satellite data to help prevent and mitigate natural disasters and ultimately contribute to climate crisis adaptation. Finally, BEYOND in collaboration with the PRAXI/FORTH Hellenic network operating in the framework of the "Caroline Herschel Framework Partnership Agreement on Copernicus User Uptake-FPCUP" has been organizing presentations in Greek schools for introducing students to the European Copernicus programme and demonstrating the various applications of its EO satellites, which actively contribute to Europe's sustainable development objectives.

In the context of the aforementioned national and international advancements, we developed and present here an EO-based learning scenario that was implemented in different Greek primary schools as a "Skills Laboratory", and it was later included in the approved list of programmes proposed to the Greek teachers by the Institute of Educational Policy of the Greek Ministry of Education [32]. The learning scenario is not intended to teach EO and remote sensing, but rather to demonstrate how a real-life EO-based scenario can act as an entry point for space data into primary school education, attract EO newcomers, and thus increase its visibility within the educational community. Furthermore, it was intended to indicate potential benefits of EO for CCSE.

The main research question to be answered in this study is whether an EO-based educational scenario, consisting of a coherent sequence of learning activities for a climate change-related impact, could effectively be implemented in the framework of the Greek primary school curriculum by teachers and students with no prior EO knowledge of any kind, no external guidance or assistance, based solely on self-explaining, written instructions. Specifically, we examine whether such an EO-based scenario:

- Attracts and maintains student interest;
- Inspires students to explore satellites and EO further;
- Raises climate change awareness and enhances student understanding of the size of natural hazards' impact through the combined global, local, and diachronic perspective it offers;
- Promotes teacher upskilling through the use of EO-based applications and novel pedagogical approaches, such as phenomenon-based, place-based, and inquiry-based teaching and learning;
- Establishes links to different topics of the Greek school curriculum, enabling students to make sense of concepts taught at school beyond the classroom context.

Although this is a nationally contextualized study, we expect that our research findings provide useful input to a wider audience interested in utilizing EO for CCSE in schools.

In Section 2, we introduce the EO-based learning scenario, its activities, the pedagogical methods and the EO resources used, and the scenario's evaluation methodology. In Section 3, we present the scenario's implementation details in Greek schools, and the results from its evaluation by teachers and students. Our findings are discussed in Section 4 along with our conclusions and key recommendations for future actions.

2. Materials and Methods

In this section, we introduce the educational material, the pedagogical methods, and the tools it uses, along with the evaluation methodology applied during its implementation. We abbreviate the material as MaFiSS after its title "Mapping Fire Scars from Space". MaFiSS consists of a set of structured activities, aimed to be used coherently in the context of the learning process on the thematic of wildfires.

As described already, one of the main objectives of MaFiSS is to study whether EO can be exploited in the framework of the school curriculum by teachers and students with no prior EO knowledge. The material guides teachers and students to investigate wildfires as an impact of climate change from different perspectives and scales based solely on written instructions and without any external support or guidance.

The topic of wildfires was purposely selected for MaFiSS, since: (a) wildfires and their scars are well-suited for study based on EO imagery; (b) there are enough EO resources available in the Greek language for the study of wildfires, which can make classroom activities exciting and relevant to students; (c) wildfires are a real-life phenomenon for Greek students, considering that Greece is systematically being devasted by wildfires every summer; and (d) wildfires are a phenomenon inextricably linked to climate change.

Although the learning scenario begins by examining national and global wildfire episodes so that the connection with climate change can be established, it gradually steers students towards their local environment by examining how it has diachronically been affected by wildfires, which parts are repletely burned, and why. This type of gradual zooming into the local environment to which students are emotionally attached and that is imbued with meaning by their experiences aims to enhance student understating of wildfire causes and impacts and to promote environmentally responsible behavior and stewardship.

MaFiSS was designed for students aged between 11- and 15-years-old—upper primary or lower secondary school students—and it was built around their curricular needs. The complete scenario breaks down into a sequence of seven (7) learning activities (referred here as Lesson Plans), which were implemented once a week during the 45′ didactic hour, dedicated to the curricular subject of Skills Laboratories. Three (3) fifth-grade classes and a total of 57 students from Greek public primary schools located in the urban centers of Athens and Agrinion received the implementation of MaFiSS during the period spanning from December 2021 to February 2022. Specifically, the seven-week long programme was carried out by class E1 of the fifth primary school of Ilioupolis in Athens with 24 students, class E1 of the second primary school of Saint Constantine of Agrinion city with 17 students, and class E2 of the same primary school with 16 students.

In Table 1, we provide a quick overview of the lesson plans (LPs), pedagogical methods, and tools used in MaFiSS:

Table 1. Overview of MaFiSS lesson plan activities, pedagogical methods, and tools.

Lesson Plan	Activities and Tools	Learning Methods
LP-1: Did you know?	Introduces the subject of wildfires through a brief printed questionnaire designed to spark student curiosity. Following that, students collect and analyze answers using Excel and finally, search for the correct answers using printed, popularized scientific texts.	• Collaborative learning • Inquiry-based Learning (IBL)
LP-2: Hot News	Students are exposed to an attention-grabbing image of a dry storm and study the phenomenon causes, based on supportive PowerPoint material. Subsequently, they study different media reports about past wildfires that have devastated Greece for discovering previously unknown causes and impacts. Finally, they organize their newly acquired knowledge, using digital Mind Map software	• Phenomenon-based learning • Inquiry-based learning (IBL)
LP-3: Handmade, fire scar mapping	Students engage in a hands-on mapping activity of burned areas, using printed worksheets featuring satellite images which depict regions in Greece both before and after the devastating fires of 2018.	• Active, hands-on learning
LP-4: Fire scar mapping with EO browser	Students are introduced to basic remote sensing concepts and presented with tips on interpreting satellite images based on a PowerPoint presentation. Following that, students locate, analyze, and digitally map the fire scars examined in LP-3, as well as other local ones of their choice, using EO browser.	• Direct Instruction • EO-Based learning • Place-based learning
LP-5: How much has your region suffered from fires?	Students study the extent their region has been affected by wildfires diachronically, using the "Diachronic Burnt Scar Mapping" service of the BEYOND EO Center of NOA. Students visit local areas devasted by fire and reflect critically on causes, impacts, and prevention measures.	• Place-based learning • EO-Based learning
LP-6: Spread the news	Students collaboratively design and implement an awareness campaign targeted at the school or local community. They create hand-painted posters or use digital poster maker tools, PowerPoint, video editors, et al.	• Collaborative learning • Creative learning
LP-6: Evaluate	Students are guided to recall all the stages of the programme, discuss, and evaluate the learning process and its outcomes, using printed evaluation forms	• Reflective learning

2.1. Pedagogical Methods

The pedagogical foundations upon which MaFiSS is designed are the IEP's guidelines for "Skills Laboratories", which describe the learning objectives and the pedagogical approaches to be used. Any activities within this context are required to be interdisciplinary, cross-curricular, student-centered, collaborative, and connected to real-life, local, or global problems, aimed at cultivating students' 21st century skills. IEP's theoretical framework for "Skills Laboratories" complies with UNESCO's guidelines for rethinking education [8] and adopts learning and teaching approaches [33–37] well-established by research and literature, such as project-based, problem-based, inquiry-based, collaborative, authentic, and active learning.

Therefore, within the aforementioned framework, we based the design of MaFiSS on the inquiry-based learning (IBL) approach, as it is an effective pedagogical method, which involves learners constructing their own knowledge based on personal explorations that deepen their understanding of the phenomenon under study [37–39]. Additionally, it is an approach well-suited both for environmental and STEM educational activities [40,41]. Combined with IBL and other well-established learning approaches, such as collaborative and active learning [42–44], our pedagogical scenario integrates elements of the phenomenon-based and the place-based approaches, which blend naturally with IBL and are especially suited for environmental education.

In the phenomenon-based approach, students are engaged in science inquiry through a real-life "phenomenon" or an attention-grabbing image that hooks them into the lesson, stimulates them to ask questions, and provokes them to search for answers in multiple areas of science. Ideally, the phenomenon used as a springboard is local or current but, above all, is visually interesting and not easily understood at first glance [13,45,46]. For MaFiSS, we used an attention-grabbing image of a past dry storm episode in Greece. Dry storms are an uncommon but not so rare global-scale phenomenon that is well-suited for the scenario purposes as it is generally unknown, impressive, and not easily understood at first glance.

Finally, a place-based approach is utilized in MaFiSS alongside the aforementioned pedagogical methods. Place-based education promotes learning that is rooted in the students' immediate and unique environment, culture, economy, and history. It is especially suited for environmental education, as it increases what place-based educators call students' "sense of place" [47–49]. This is not to say, however, that global and national issues are peripheral to place-based education, it simply argues that it can act as a bridge between the local and the global and it can help students better understand both [50,51]. In MaFiSS, through the EO applications described hereunder, there is a constant shift between national, global, and local environments that have been harmed by wildfires. This way, students gain a full-scale understanding of the wildfire hazard and are encouraged to project their observations, experiences, and emotions of their harmed nearby places to faraway ones.

2.2. EO Tools and Resources

Regarding the choice of tools and resources for MaFiSS, the objective was to select open-access EO-based tools of reduced complexity, which require minimum or no training and can be supported by the average school infrastructure. In recent years, cloud-based applications, such as EO browser [52] and Sentinel Playground [53], are becoming commonplace. Both these applications provide users with easy access to a vast archive of satellite imagery, including daily updated data from the Sentinel satellites, Landsat, and other sources. They enable non-expert users to explore and analyze different satellite images, apply various visualization and analysis tools, create custom image composites, and thus unlock the power of EO towards a greater environmental understanding. Such tools could potentially help overcome past hardware, support, or training necessities and thus encourage teachers to incorporate EO in their teaching if appropriate learning materials are made available [17].

For the purpose of this pedagogical intervention, we chose EO browser instead of Sentinel Playground despite the latter being suggested as the most suitable for Greek schools by a recent evaluation study [54]. EO browser, unlike Sentinel Playground, was not originally built with educators in mind. However, its powerful original features and capabilities, together with its recent upgrades, have made it an appropriate choice for schools because: (a) it is a powerful, open-access, cloud-based application that has minimum hardware requirements and thus can be easily supported by the average school computer lab or classroom; (b) it requires no registration to access standard functions, which simplifies educational use, while at the same time it offers free registration for full access to all features; (c) since the mid-2020 [55], a new education mode has been added to EO browser with 12 pre-prepared themes—including wildfires—perfect for students and teachers interested in exploring our planet through EO data; (d) since the mid-2021 [56], multi-language support—including Greek—has been added to EO browser, enabling students to work in their native language and thus overcome barriers, which may have previously discouraged them from searching, visualizing, and studying satellite imagery; (e) it offers a wealth of functions to users that pass the novice stage and want to delve into more advanced explorations; and (f) it offers fast availability of fresh data, often within a few hours after the acquisition, enabling educators to incorporate up-to-date events and phenomena in their teaching. As such, EO browser was considered here as the most appropriate EO-based tool for school level education that made it possible for absolute beginners to unlock the power of EO.

The second resource utilized in the educational scenario is the "Diachronic Burnt Scar Mapping" (Diachronic BSM) tool [57], which is part of the FireHub suite of web services, offered by the Operational Unit "BEYOND Center for EO Research and Satellite Remote Sensing" of the National Observatory of Athens in Greece (NOA) [58]. Diachronic BSM is a map-based inventory of wildfires, which depicts the results of the diachronic mapping of burned areas over Greece for the last 35 years. Although this tool, once again, was not built with educators in mind, it provides a unique view of all the wildfires that have devastated Greece in the last 35 years. Such information is valuable for the learning objectives of the educational scenario, and despite the tool's scientific look and feel, students can use it for cataloging wildfires in their region since their interaction with the tool is simple and straight forward.

2.3. Educational Material-Lesson Plans

The educational scenario of MaFiSS contained a structured plan of activities to be used coherently in the context of the learning process. The flow of learning activities in the form of lesson plans (LPs) is described in detail hereunder.

2.3.1. LP-1: "Did You know?"

LP-1 introduces the subject of wildfires by engaging students in a small-scale internal investigation of their prior knowledge and experience with wildfires through a brief questionnaire. The questionnaire contains both open-ended as well as close-ended questions, which are accompanied by short and usually mutually exclusive answers so that students can subsequently analyze their answers before the end of the class (see full questionnaire and correct answers in Appendix B).

Apart from collecting input on students' prior knowledge and experience, the questionnaire mainly aims to pave the way for the inquiry process that follows. To this end, some questions are intentionally provocative or contain surprising elements, aiming to puzzle students, spark their curiosity, and stimulate their interest for further investigation of the subject. Such type of questions is, for example:

Q.1 Which of the following conditions help wildfires spread faster? Choose as many answers as you think apply: Strong winds/High temperatures/High humidity/Up-hill terrain/Dry vegetation/Down-hill terrain.

Q.4. In which of the following areas of the world do you think most wildfires occur? Choose only one answer: African forests and savannas/Amazon tropical forests/Mediterranean forests/Boreal forests.

After filling out the questionnaire, students start working collaboratively in groups. One group collects and analyzes student answers using the provided worksheet, focusing on simple descriptive, percentage-based analysis, while the other groups engage in a discovery learning process by searching for the correct answers to the survey questions. To support and boost students' performance during the inquiry learning process, we provide scaffolds in the form of adapted scientific texts, which guide them to make discoveries about the issues raised in the questionnaire but also mobilize their reflection and critical thinking skills (see Figure 1).

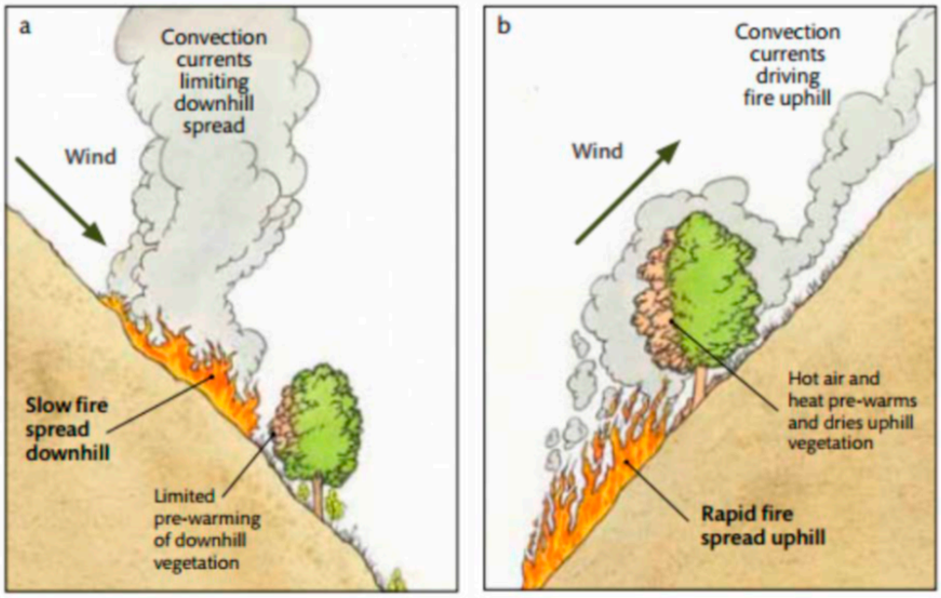

Figure 1. Translated excerpt from the adapted scientific texts given to students in order to support their enquiry learning process. The effect of slope on fire behaviour: (**a**) a low-risk 'creeping fire' burning slowly downhill, and (**b**) a dangerous 'running fire' burning rapidly uphill Image credit: Forestry Commission 2014 Practice Guide in https://cdn.forestresearch.gov.uk/2014/03/fcpg022.pdf (accessed on 23 September 2023).

The lesson plan concludes with students presenting their discoveries and discussing their findings in comparison to their original answers.

2.3.2. LP-2: "Hot News"

LP-2 uses elements of the phenomenon-based learning approach as springboard for the second lesson plan in order to increase the desire of students to delve naturally into the subject of extreme weather in relation to climate change and wildfires. Students are exposed to an attention-grabbing image representing the dry storm that hit the Thasos Island in 2016 (see Figure 2) and are encouraged to challenge their ideas, ask questions, and collectively study the phenomenon based on the supportive material provided.

After the study of the dry storm phenomenon and its relation to climate change and wildfires, the teaching scenario shifts to the collaborative study of different media reports about wildfires that have devastated Greece in the past. Through the study of the carefully selected and adapted media reports, students are expected to discover previously unknown causes and impacts of wildfires, but also to engage in an ecocritical and ethical reflection process when they share thoughts and feelings on questions about who benefits, who/what suffers, and how they suffer. Such questions help them cultivate their empathy and sensitivity skills. At the end, students record and organize their newly acquired knowledge about wildfires in a conceptual map.

2.3.3. LP-3: "Hands-on Fire Scar Mapping"

LP-3 encourages students to actively engage in a hands-on mapping activity of burned areas based on satellite images of the Mati and Kineta areas of Greece before and after the catastrophic fires of 2018. For this purpose, two similar sets of worksheets are provided, containing high-resolution Sentinel-2b images in the visible wavelengths as well as step-by-step instructions that guide students to locate and calculate the burned areas in a simple and intuitive manner (see Figure 3). Students work in pairs—one works on the Kineta worksheet and the other on Mati—facing different challenges in their effort to locate the boundaries of the fire scar, calculate the area burned, and convert it to different measurement units. This is intentionally designed to demonstrate different types of difficulties encountered during satellite fire scar mapping in terms of image scale, clarity of the fire scar, etc.

Figure 2. Attention-grabbing image used as a springboard in the 2nd lesson plan, based on the phenomenon-based learning approach. Image credit: pexels.com, (accessed on 22 September 2023).

Through this activity, students are expected to: (a) cultivate their mathematical and geometry skills; (b) discover the paramount importance of satellite remote sensing for mapping burned areas quickly and economically; (c) familiarize themselves with satellite imagery "reading" and interpretation; and (d) recognize the difficulties in locating fire scars in densely populated areas compare to forest areas. After having completed the activity, each pair of students announces the results of their work in class. Results are recorded and compared with the official mapping data available in the teacher's supporting material, which also describes the expected difficulties and causes of deviations in the student calculations, thus guiding the teacher to provoke a reflective discussion.

2.3.4. LP-4: "Fire Scar Mapping with EO Browser"

LP-4 gives students the opportunity to dig deeper into the world of satellite remote sensing after their initial contact with satellite imagery during the previous activity. To begin with, students watch a 10-slide long introductory presentation that explains the basic concepts of EO and provides simple tips on how to interpret satellite images (Figure 4).

After the preparatory presentation and discussion, students get the chance to observe our planet from space and, for the first time, actively explore satellite observations by interacting with EO browser, the web application of Sentinel Hub services that offers all citizens free access to satellite imagery from open satellite data providers. Through this easy-to-use application, which has recently incorporated an education mode and supports the Greek language, students are able to browse and analyze satellite visualizations and thus cultivate their digital skills and enhance their EO science understanding. The learning scenario, at first, allows for a familiarization phase, where the teacher demonstrates the use of the EO browser based on the provided, step-by-step instructions, which describe the process of how to locate the areas of Kineta and Mati, how to interpret what you see in satellite images, how to compare before and after fire visualizations, and how to digitally map the burned areas.

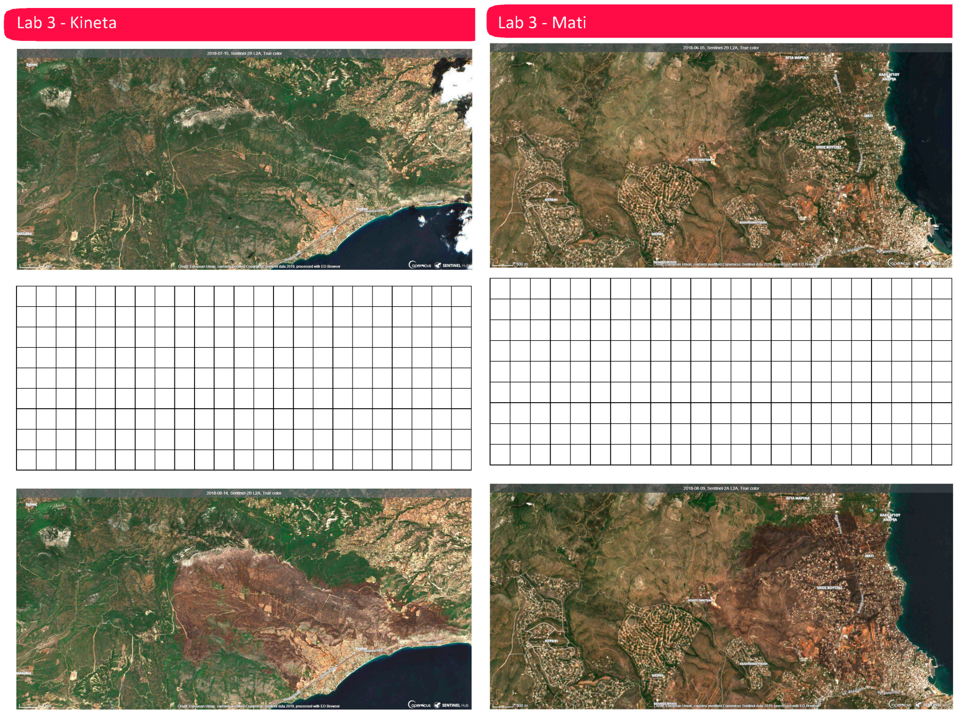

Figure 3. Excerpts of the fire scar mapping worksheets used for calculating the burned area in Kineta (**left**) and Mati (**right**). Each worksheet is accompanied by explicit step-by-step instructions that help students complete the activity.

Following the demonstration, students get their hands on EO browser and try to locate and digitally map the scar of the wildfire that devastated northern Evia Island in the summer of 2021. The northern Evia wildfire has been intentionally selected because its recent, it attracted major media attention and it left a clearly observable scar that students can easily identify and map, following another set of step-by-step instructions. Optionally, students are given further instructions as to locate and map the fire scar of the 2020 megafire in the area of Magaras in Yakutia Russia in order to gain a deeper understanding of the magnitude wildfires have globally and the power of EO to depict all the events, independently of spatial scales.

2.3.5. LP-5: "How Much Has Your Region Suffered from Fires?"

LP-5 engages students in a diachronic scale investigation of local wildfires. Students, for the first time, focus on their local area and examine whether and to what extent their region has been affected by wildfires. Using the "Diachronic Burnt Scar Mapping" web service, offered by the BEYOND EO Center of NOA, students can visually comprehend the diachronic impact of wildfires in Greece since 1984. Starting with a nationwide view, students can simply zoom in their area of interest and thus gain instantly a better understanding of the magnitude of the wildfire hazard (Figure 5). Based on the provided worksheet, they are then guided to catalog each local fire and search for more information related to major local fires in the digital local press. In the discussion that follows, students are encouraged to share their likely experiences, locate areas that are burned repeatedly, and reflect critically on the causes. Finally, they discuss possible prevention measures for their region.

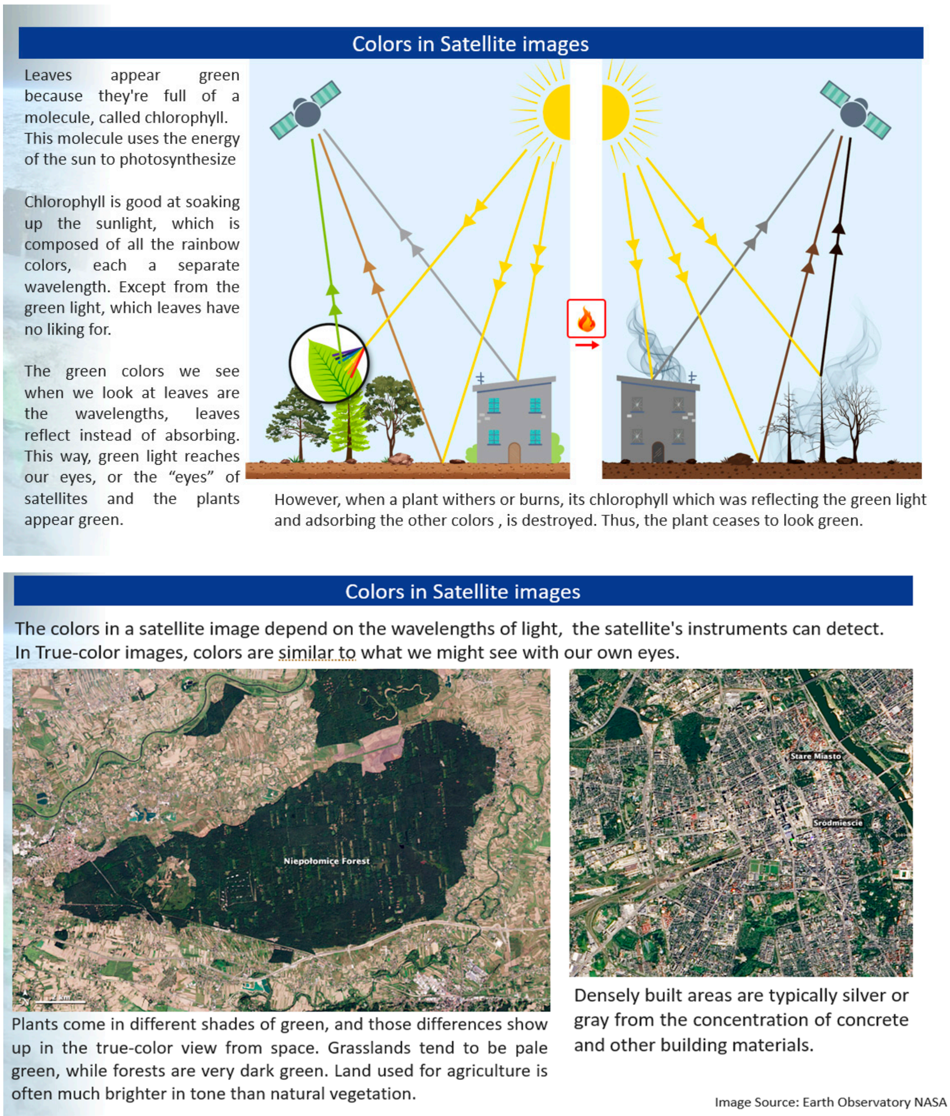

Figure 4. Excerpts from the introductory student presentation on basic EO concepts, such as light reflection properties of burned areas (**top**) and various unburned areas (**bottom**).

2.3.6. LP-6 and 7: "Evaluate What You Learned and Spread the News"

The final two lesson plans of MaFiSS (LP-6 and LP-7) focus on collaboratively designing and implementing an awareness campaign targeted at the school or local community. Additionally, these plans involve evaluating the overall effectiveness of the MaFiSS pedagogical programme (see Section 3).

During LP-6 and 7, students are guided to recall all the stages of the programme, discuss the process and its outcomes, gather the products of their work, and consider how to use them in their dissemination and awareness campaign. With the help and the guidance of their teacher as well as the arts teacher or the Information and Communication Technology (ICT) teacher, students, in the two didactic hours available, create posters, flyers, ppt presentations, or podcasts or sort videos through which they activate their creativity and cultivate their communication, cooperation, and digital skills.

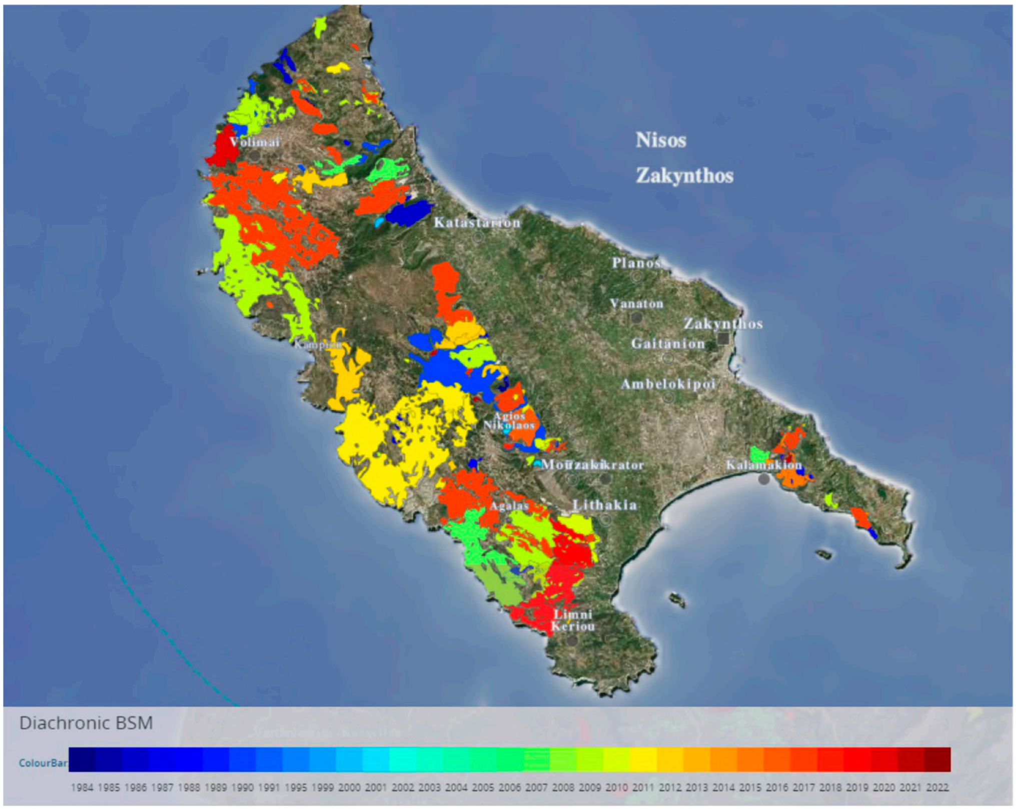

Figure 5. Snapshot from the Diachronic BSM tool of BEYOND FireHub, used by the students to study local wildfires.

2.4. Evaluation Methodology

During each stage of the MaFiSS implementation, following each lesson, teachers were requested to submit photographs of all student-generated products, such as mind maps, questionnaires, worksheets, posters, etc. Moreover, they were required to provide their post-lesson feedback through a telephone interview.

Towards programme completion (at LP-7), teachers were requested to assess the entire programme using an evaluation form comprising a set of closed–ended and open-ended Teacher Feedback Questions (TFQs). For the close-ended questions, a typical 5-point Likert scale was employed with a midpoint neutral option (1 = Not at all, 2 = a little, 3 = fairly, 4 = A lot, 5 = Very much) aiming to gauge teachers' perceptions of the program. The open-ended questions complemented the closed-ended ones, enhancing the reliability of the measured opinions and facilitating the collection of valuable qualitative data (see teacher evaluation questionnaire, and results in Section 3.1).

The teacher evaluation process aimed to:

- Determine if MaFiSS is sufficiently self-explanatory, and user-friendly for teachers with no prior EO knowledge to implement independently without the need for external support or guidance;
- Evaluate whether the educational scenario, according to teachers, attracts and maintains student interest;
- Evaluate MaFiSS' adaptability in meeting the specific requirements of different schools for highlighting the local effects of wildfires;
- Investigate whether the programme stimulates students' and teachers' interest for satellites and EO;
- Evaluate whether, according to teachers, the EO-based approach enhances students' understanding of wildfire magnitude through the combined global, local, and diachronic perspective it offers;

- Assess how well the different learning approaches (i.e., EO-based, phenomenon-based and place-based) work together in synergy, complementing each other;
- Investigate whether links between MaFiSS and concepts taught at school are established, enabling students to make sense of them beyond the context of the respective curricular subjects.

Concurrently with teachers (at LP-7), students were also asked to evaluate the entire programme based on the Student Evaluation Questionnaire (SEQ), which contained a blend of open- and closed-ended questions. A “forced choice” 4-point Likert scale was used for the close-ended questions (1 = not at all, 2 = a little, 3 = fairly, 4 = a lot) in order to measure students’ opinion and sentiment regarding the programme (see student evaluation questionnaire in Section 3.2).

The student evaluation process aimed to:

- Examine whether the EO-based approach helps raise awareness and understanding of climate change impacts such as wildfires (environmental objectives);
- Record students’ awareness and prior knowledge regarding satellites, EO, and space-based information and tools (STEM and EO objectives);
- Assess students’ interest stimulation level for satellites and EO (EO and STEM objectives);
- Examine the degree of relevance between MaFiSS and the Greek school curriculum based on the level of associations and connections made with existing curricular topics (curricular objectives);
- Measure students’ programme satisfaction (satisfaction objectives).

3. Results

Here, we present the first application of MaFiSS to 57 fifth-grade students distributed across three primary school classes situated in Athens and Agrinion, and we discuss the initial results from the teachers’ and students’ programme evaluation. It must be noted here that due to the COVID-19 pandemic and the seven-week-long implementation period of the programme, a small number of students (between 5 and 7) were absent during certain lessons, which created some gaps in these students’ perception of the programme.

Out of the three teachers implementing the programme, two were primary school teachers and one of them was a drama teacher (theater studies). They all had previously implemented other environmental projects about wildfires but had no prior knowledge of satellites and EO nor they were aware of the applications used in the programme. They all received the description of the programme, student worksheets, and supportive material and implemented it according to their understanding and with no further guidance or help.

3.1. Teacher Evaluation Results

In Table 2, we provide a summary of the MaFiSS evaluation questions along with the respective teachers’ responses. Close-ended questions are abbreviated as TFQs, and supporting questions are noted.

Table 2. MaFiSS evaluation close-ended and supporting open-ended questions and teacher responses (n = 3).

Question Category	Teacher Feedback Question	Answers & Frequency
Material's teacher-friendliness	TFQ.1: Were the scenario and the instructions clear and easy to follow, enabling you to independently implement MaFiSS?	• A lot: 3
Degree of teacher preparation	TFQ.2: To what extent did you need to prepare for the implementation of each lesson?	• Fairly: 2 • A little: 1
Infrastructure requirements	TFQ.3: Was your school's technical infrastructure, adequate for the implementation of MaFiSS?	• A lot: 2 • A little: 1 [1]
Lesson time sufficiency	TFQ.4: Was the lesson time generally sufficient for the completion of the activities of each LP?	• A lot: 2 • Fairly: 1
Lesson time sufficiency	TFQ.4 Supporting: Which activities, if any, exceeded the lesson time and how did you manage to complete the activities?	• LP-4: 3 [2] • LP-6: 3 [3]
Material age appropriateness	TFQ.5: Was the pedagogical material age appropriate for your students?	• Very much: 3
Programme attractiveness	TFQ.6: Was the programme attractive and engaging for your students?	• Very much: 3
Programme attractiveness	TFQ.6 Supporting: Which activities, if any, were the most attractive and engaging for your students?	• LP-2: 3 • LP-4: 3 • LP-6: 3
Programme attractiveness	TFQ.6 Supporting: Which activities, if any, didn't manage to maintain student interest and why?	• LP-1: 3 • LP-7: 3
Implementation difficulties	TFQ.7: Did you encounter any difficulties during the implementation of MaFiSS?	• Not at all: 2 • Fairly: 1
Implementation difficulties	TFQ.7 Supporting: What kind of difficulties did you face?	• Lacked tech infrastructure: 1 [1]
Phenomenon approach effectiveness	TFQ.8: Did the phenomenon-based approach in LP2-dry storm- attracted student interest and provoke reflection?	• Very much: 3
Educational Suitability of EO Apps	TFQ.9: Do you consider the EO-based applications utilized in MaFiSS easy to use and suitable for educational purposes?	• Very much: 3
Educational Suitability of EO Apps	TFQ.9 Supporting: Did your students have the chance to interact personally with the web applications EO Browser/Beyond FireHub?	• Yes: 2 [2] • No: 1 [2]
EO-based approach effectiveness	TFQ.10: To what extent, the use of satellite images and EO-based applications helped your students grasp the scale, magnitude, and timelessness of the wildfires' phenomenon both at local and global level?	• A lot: 2 • Fairly: 1
Student EO interest impact	TFQ.11: Did you observe any increase in your students' interest for space, satellites and EO technology?	• A lot: 2 • Fairly: 1
Student EO interest	TFQ.11 Supporting: How was that interest manifested?	• See Section 3.1.6

Table 2. *Cont.*

Question Category	Teacher Feedback Question	Answers & Frequency
Links to curricular topics	TFQ.12: Did MaFiSS helped you enrich or broaden the scope of the curricular subjects you teach?	• A lot: 2 • Not at all: 1
Links to curricular topics	TFQ.12 Supporting: Which of the subjects you teach benefited and how?	• See Section 3.1.7
Teachers' satisfaction	TFQ.13: Did the program material meet your expectations?	• Very much: 3
Teachers' satisfaction	TFQ.14: Would you recommend MaFiSS to a colleague?	• Very much: 3
Recommendations for improvement	TFQ.15: What would you recommend for improving the material?	• Shortening of student texts: 3

[1] This teacher's classroom lacked the basic laptop and projector infrastructure and had to borrow and set up the required equipment during the lesson. [2] LP-4 required students' personal interaction with EO browser, for which lesson time was insufficient, thus two of the teachers collaborated with the school's ICT teacher and extended the activity into the ICT lesson. The 3rd teacher skipped students' personal interaction and focused on tool demonstration.[3] LP-6 prompted for the design of an awareness campaign. In this case, one class collaborated with the school's art teacher for the campaign design, and extended LP6 into the art lesson, and the other two classes extended the activity into the ICT lesson.

In the following sub-sections, we outline the key points and trends identified in teachers' responses:

3.1.1. Material's Teacher-Friendliness and Ease of Implementation

Considering that teachers evaluated MaFFiS as user-friendly, there is a good indication that any teacher at any school, with no prior knowledge on EO and with basic classroom technical infrastructure—laptop and projector—can effectively implement MaFiSS or similar EO-based pedagogical scenarios. According to teachers' testimonies, who deemed the material clear and easy to implement, "It sounded high tech at first, but it was straight forward once you read it". They all confirmed that the student material was detailed, organized, and ready-to-use, requiring just a fair amount of teacher preparation time mainly for familiarizing themselves with the EO based applications. However, one didactic hour was not sufficient for certain activities, and the implementation had to be extended into the ICT lesson.

3.1.2. Programme Attractiveness and Student Engagement

In TFQ6, we asked the teachers "Was the programme attractive and engaging for your students?", and they all rated MaFiSS positively. According to their testimonies: (a) "Even students that are usually disengaged during most lessons, exhibited great interest and participated actively" and "Students worked with great enthusiasm and quietly which hardly ever happens." Based on their responses to the supporting questions about the most and the least attractive and engaging activities for students, they rated them as follows:

- Maximum attractiveness and engagement: (i) LP2: dry storm phenomenon and fire disaster press reports; (ii) LP4: EO browser interaction and (iii) LP6: awareness campaign. The success of these lessons was mostly attributed to the impressiveness of the dry storm phenomenon in LP2, the novelty of interacting with EO browser in LP4, and the creative characteristics of LP6.
- Medium attractiveness and engagement: Students exhibited medium interest for LP3 which mainly used fire scar calculation worksheets (see Appendix C.2) and LP5 where students were required to catalog past local wildfires through the Diachronic BSM of Beyond FireHub application (see Appendix C.4). As reported by all teachers, mathematical calculations discouraged quite a few students in LP3 while in LP5 the static nature of the application caused a gradual decrease of interest.

- Minimum attractiveness and engagement: The least favorite activities were the ones contained in LP1: questionnaire completion, analysis of answers, and scientific inquiry, together with the programme evaluation activities in LP7 at the end of the programme.

3.1.3. Suitability of EO Tools for Education

All teachers affirmed that the EO-based applications utilized in MaFiSS were easy to use and suitable for educational purposes. Teachers, whose students interacted personally with EO tools in ICT lesson, emphasized how intuitive the EO browser was and how quickly students and teachers familiarized themselves with the application after reading the written instructions. As an example, soon after LP4 was implemented and after Athens was hit by the unprecedented snowstorm "Elpis" on the 24 January 2022, students in one of the classes put their newly acquired skills and knowledge into use outside of the scenario's framework and proceeded to observe the snowstorm from space, comparing before and after images (see Appendix C.3).

3.1.4. Effectiveness of the Phenomenon-Based Approach

Regarding the use of the phenomenon-based approach and specifically the dry storm phenomenon, all teachers agreed that it was impressive and provoked the students' interest and curiosity. Student evaluation results also confirm the teachers' perception that the phenomenon-based approach stimulated the interest in the classroom.

3.1.5. Effectiveness of the EO-Based Approach

As for the effectiveness of the EO-based approach in helping students grasp the scale, magnitude, and timelessness of the wildfires' phenomenon, teachers consented that the approach raised their students' level of awareness significantly, especially at the local level. According to their testimonies "We all knew wildfires are frequent and extensive in Greece but when you study the EO images of fire scars, when you measure the areas burned, and when you catalog past wildfires in your region, you realize fully the magnitude of the problem", "This work had an impact on our students who passionately campaigned in the local community against wildfires and created posters that portrayed their feelings and their newly acquired awareness" (Figure 6).

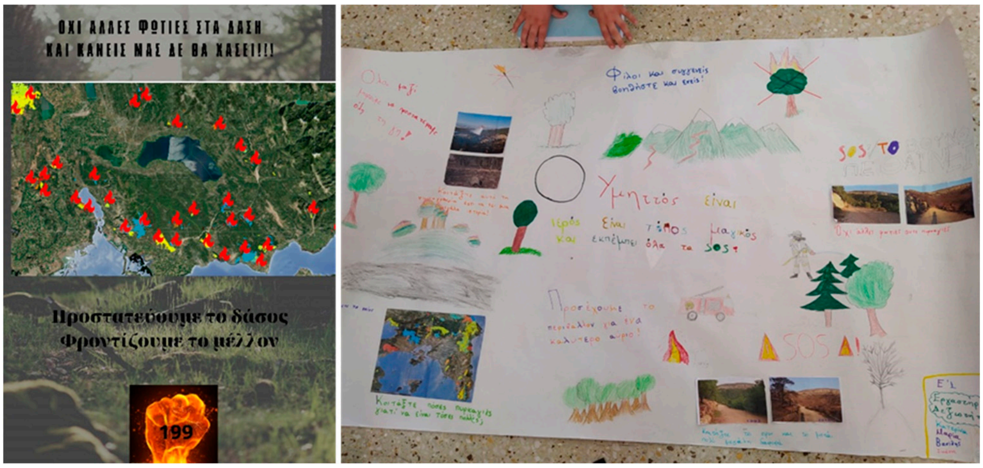

Figure 6. Samples of different student posters, campaigning against wildfires. On the **left**, a digital poster with slogans in Greek that read (starting from the top) "No more wildfires in our forests" and "Protecting our forests, protects our future". Students have also added red flames on the Diachronic BSM map in all areas burned over the past years in their region. On the **right**, an example of a handmade poster in Greek.

3.1.6. Impact on Student Interest for Satellites and EO

Regarding the impact of MaFiSS on student interest for satellites and EO, all teachers affirmed that student interest was increased considerably. They noted that students started asking questions about satellites they could not answer and that they all studied with great interest the optional supplementary material "Teach with Satellites", which contains basic, simplified information about the etymology of satellites, the history of the technology, the types of satellites, how they are put into orbit, etc. (Figure 7). Furthermore, some students started searching for NASA and ESA videos about satellites on YouTube and shared their findings in class. Lastly, during the evaluation phase at the end of the programme, students themselves expressed their enthusiasm towards satellites and EO.

Figure 7. Students in Agrinion (**left**) and Athens (**right**) studying the optional supplementary material "Teach with Satellites" after the completion of the MaFiSS activities.

3.1.7. Links to Curricular Concepts

As for the potential correlations between MaFiSS and the curricular subjects taught at Greek schools, all teachers, except the drama teacher, reported that MaFiSS helped them expand the scope of the subjects they teach and helped their students connect curricular concepts with real-life contexts. Specifically, they linked the programme with physics topics, such as the "Heat Energy" and "Electricity"; geography topics, such as "Maps" and "Orientation"; and mathematical topics, such as "Area measurement units". Additionally, teachers expressed the intention to use the programme for enhancing and modernizing topics scheduled for later teaching, such as: (a) "Natural disasters" topics in geography; (b) the topic of "Light" in physics; and (c) the «Space travel, what we see from space» topic in the Greek language subject, where satellite pictures from Space Shuttle Endeavour are used in the textbook to introduce EO to students.

3.2. Student Evaluation Results

In Table 3, we list the closed-ended questions (SEQs) answered by students, summarizing the results. Following that, the main findings from the analysis of the SEQs are presented together with the students' responses to the open-ended questions used in the evaluation process.

Table 3. Student responses (n = 52) to the SEQ questions used during the programme evaluation phase.

Objectives Category	SEQ Questions	Not at All	a Little	Fairly	a Lot
Environmental	SEQ.1: Did you learn new things about wildfires that you were not aware before?	0%	0%	48%	52%
Environmental	SEQ.2: Did satellite imagery and tools help you better understand the magnitude and severity of the wildfire hazard?	0%	8%	21%	71%
Environmental	SEQ.3: Did satellite imagery and tools help you better understand how your region has been affected by wildfires in the past?	0%	4%	31%	65%
Environmental	SEQ.4: Can you explain to others (parents or friends) how climate change is affecting wildfires and vice versa?	6%	29%	54%	12%
EO & STEM	SEQ.5: Prior to your participation in this programme, how much did you know about satellites and Earth Observation?	31%	58%	12%	0%
EO & STEM	SEQ.6: Did you learn interesting new things about satellites and the way they monitor earth from space?	0%	12%	31%	58%
EO & STEM	SEQ.7: Would you like to learn more about satellites and the way they monitor earth from space?	2%	12%	35%	52%
Curricular	SEQ.8: Did the programme help you better understand topics you are taught in other curricular subjects (such as optics, human vision, photosynthesis, Greek language etc.)?	6%	13%	54%	27%
Curricular	SEQ.9: Did the programme applications help you improve your map navigation and orientation skills?	4%	23%	50%	23%
Satisfaction	SEQ.10: Were there impressive features in the programme that didn't expect to find at the start?	0%	8%	29%	63%
Satisfaction	SEQ.11: How much did you like the programme?	0%	6%	33%	62%
Satisfaction	SEQ.12: Would you like to participate in similar EO-based programmes in the future?	0%	12%	29%	60%

It must be noted that, although a total of 57 students implemented the seven-week-long programme, due to COVID-19-related absences, only 52 students were present during LP-7, and thus, we only received 52 student evaluations (16 evaluations from class E1 in Agrinion, 15 evaluations from class E2 in Agrinion, and 21 from class E1 in Ilioupolis).

By analyzing the responses to the questions related to the environmental objectives in Table 3, it is evident that the EO-based approach of the programme raised student's awareness and understanding of climate change impacts, such as the wildfire hazard. Specifically, the majority of students (71%) stated that satellite imagery and tools helped them "a lot" in understanding the magnitude and severity of the wildfire hazard. Most students (65%) also affirmed that the EO-based approach helped them "a lot" to understand how their region has been affected by wildfires diachronically, and 31% said it helped them "fairly". Finally, all students declared that they learned either "a lot" (52%) of new facts about wildfires they were not aware of before or "a fair" amount (48%). However, only 12% of students felt they could explain with "a lot" of confidence how climate change is affecting wildfires and vice versa while the majority (54%) felt “fairly” confident, 29% felt “a little” confident, and 6% did not feel at all confident.

As for the questions related to the EO and STEM objectives in Table 3, such as the students’ awareness and prior knowledge of satellites and EO, their answers show that the vast majority knew “a little” (58%) to “nothing at all” (31%), and only 12% claimed they knew a fair amount. After the implementation of MaFiSS, however, the largest part of students declared that they learned “a lot” (58%) or “a fair” amount (31%) of interesting things about satellites and EO. Only 12% of students declared they learned “a little”. Likewise, the largest part of students expressed their desire to learn more about Earth monitoring from space (52% “a lot” and 35% “fairly”) while a small part of students showed little or no interest in learning more (12% “a little” and 2% “not at all”).

Regarding the curricular objectives and, specifically, the interdisciplinary connections between the MaFiSS and different school subjects, half of the students (54%) thought it helped them “fairly” to better understand topics such as optics, photosynthesis, human vison, etc., and the rest were split between being helped either “a lot” (27%) or little (13%) to not at all (6%). Similarly, for map navigation and orientation skills, half of the students (50%) thought they were helped “fairly” and the rest either “a lot” (23%) or “a little” (23%) to “not at all” (4%).

Finally, for the overall evaluation of the pedagogical scenario, the majority of students (63%) thought that the programme had “a lot” of impressive features they did not expect or a “fair” amount (29%). They affirmed that they liked it “a lot” (62%) or fairly (33%), and they declared their interest for participating in similar EO-based programmes in the future (“a lot” by 60% and “fairly” 29%). No student rated MaFiSS negatively on any of these three questions, and only a small percent of them (6%) liked MaFiSS “a little” or thought that it had few impressive features (8%).

A comparative analysis of students’ top answers (“a lot”) revealed a differentiation pattern between the different classes in the case of EO-related questions as well as questions related to the overall evaluation of MaFiSS. Specifically, it was found that students from the Athens class systematically rated such questions less positively compared to the students from the Agrinion classes (see Figure 8).

The largest deviation was observed in the last question, SEQ.12: “Would you like to participate in similar EO-based programmes in the future?”, where the Agrinion students who had the chance to interact personally with the EO browser for a whole didactic hour (see Figure 9) rated this question much more positively (74% for “a lot”) compared to the Athens students who only watched an EO browser demonstration by the teacher, and their rating for “a lot ” was 38%. Smaller but considerable deviations can be seen in other questions, such as the SEQ.02: “Did satellite imagery and tools help you better understand the magnitude and severity of the wildfire hazard?”, to which the Agrinion mean student rating for “a lot” was 78% while the Athens mean student rating for “a lot” was 62%. This finding, supported by the feedback from teachers, could be an indication that personal interaction with EO tools increases awareness of climate change impacts but, more importantly, increases the desire to learn more about satellites or to participate in similar EO-based programmes.

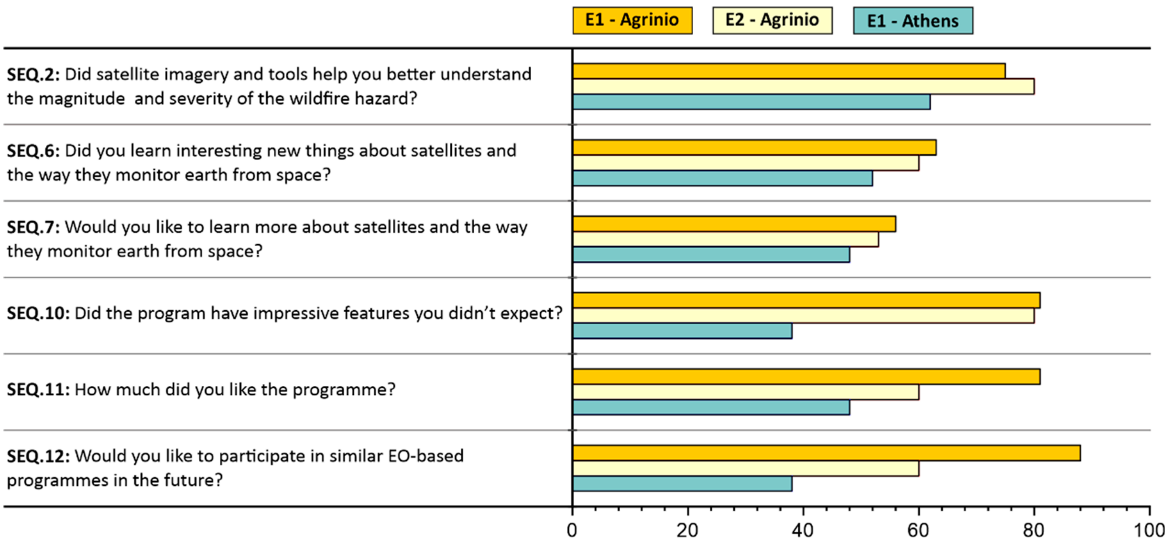

Figure 8. Comparative analysis of programme evaluation ratings between the different participating classes, referring to the top answer only ("a lot").

Figure 9. Agrinion students interacting personally with EO Browser during the ICT lesson.

On the other hand, in the case of questions related to the correlations between MaFiSS topics and different curricular topics, comparative analysis of student answers revealed random differentiations across all three classes. For example, on the question SEQ.8: "Did the programme help you better understand (optics, human vision, photosynthesis etc.)?", ratings for "a lot" varied significantly between classes (E1-Agrinion 50%, E2-Agrinion 20%, and E1-Athens 14%). It therefore seems that it is entirely up to the teachers' background studies, skills, and objectives whether they will emphasize and link MaFiSS topics to the curricular topics they teach.

Last but not least, an analysis of the students' responses to the open-ended questions reinforces the teacher feedback and evaluation findings. Specifically, on the question

"SEQ.13: Which activities did you like the most and why?" most students chose LP4: EO browser interaction, followed by LP6: awareness campaign and lastly LP2: dry storm phenomenon and fire disaster press reports. According to students' testimonies they wrote: "I loved looking for burned areas with the help of satellites, because it felt like I was floating in space looking down on earth", "I liked mostly the applications because I like technology and space", and "I liked scanning for burned areas with satellites because I could see how much they were burned". On the question "SEQ.14: Which activities did you like the least and why?", students responded that "we liked them all because they were all different and unique". A few students, however, mentioned some least favorite activities, such as LP3: fire scar calculation worksheets and LP1: questionnaire, statistical analysis, and scientific inquiry, because in both cases, it reminded them of mathematical or geometry problems they face at school. According to their testimonies "I didn't like as much the fire scar calculation worksheets because I miscalculated badly the burned area".

Finally, in relation to the question "SEQ.15: What new words and concepts did you learn?", the most popular answers are summarized in Table 4.

Table 4. Summary of new words and concepts students retained at the end of MaFiSS (n = 52).

No of Words or Concepts	New Words or Concepts	Percentage of Answers			
		Mean: 52 Answers	E1-Agrinion: 16 Answers	E2-Agrinion: 15 Answers	E1-Athens: 21 Answers
1	Dry Storm	65%	88%	87%	33%
2	EO Satellites	52%	63%	47%	48%
3	Word cloud application	31%	100%	0%	0%
4	ESA	29%	94%	0%	0%
5	Hectares (ha)	29%	94%	0%	0%
6	Fire scar mapping	21%	7%	47%	14%
7	Arson, Fire fuel, how fire spreads faster uphill [1]	17%	0%	33%	19%
8	Active reforestation	13%	0%	47%	0%
9	Fire-hub application	12%	0%	0%	29%
10	Light properties and optics (light reflection and absorption, how we see colors etc.)	10%	0%	0%	24%
11	Climate change	6%	0%	20%	0%

[1] see analysis in Appendix C.1.

Based on the spontaneous student answers to the aforementioned question ("SEQ.15: What new words and concepts did you learn?"), we could potentially deduce the following:

- The terms and concepts students consider striking and novel are acquired and retained to a great extent. Specifically, it is evident that the dry storm phenomenon made a lasting impression to 65% of the students, followed by EO satellites (52%).
- Applications that enable students to express themselves creatively, such as a word cloud, also made a lasting impression (mean 31%). Please note that only one class (E1-Agrinion) used this application (mentioned 100%).
- Terms such as fire scar mapping, ESA, and hectares left a medium impression to students (21–29%). The acquisition and retention of concepts and terms such as ESA and hectares (29%), we can safely say, is an exception, as it appears only in the answers of one class (E1-Agrinion) and, therefore, can most likely be attributed to the teacher's persistence and emphasis.
- Concepts and terms about the fire properties, optics, and climate change left a small impression.

4. Discussion and Conclusions

As cloud-based EO tools are evolving, some of the technical and language barriers holding back EO exploitation in schools previously are being gradually diminished. Nevertheless, there is more to be done in the future, for CCSE or STEM education to capitalize on EO. In [16,17], authors have concluded that one of the largest concerns for the applicability of EO in schools is the content and how the materials can be adapted to the school curricula. Given that teachers are regarding EO as highly specialized and of a technical nature [18] and feel like they are stepping into uncharted territory, paying extra attention to how coherently the pedagogical content is presented should be regarded as a top priority.

Our study shows that EO can effectively be utilized by EO novice teachers and students in everyday school reality, even at the primary level, when appropriately designed EO-based pedagogical content is available. Furthermore, our study provides the first evidence that the exploitation of EO in schools benefits CCSE as it raises student awareness and helps students better understand the scale, magnitude, and timeliness of CC hazards. The elements that seem to make pedagogical content attractive to EO newcomers and effective for CCSE are the coherence of its activities, its curricular relevance, the use of intuitive EO tools that have minimum infrastructure requirements, the use of modern learning approaches, and the utilization of real-life, attention-grabbing phenomena.

Specifically, the implementation of our EO-based learning scenario, MaFiSS, in Greek schools demonstrated that:

1. Cloud-based EO tools, such as the EO browser, are suitable for school use by EO-novice teachers and students who can very quickly become familiar with them and grasp the basic EO concepts, guided solely by written instructions;
2. CCSE benefits from the combined use of the EO-based and the place-based approach as it helps bridge the local and the global perspective of CC impacts, such as wildfires, and thus help students better understand both. The EO-based approach not only enables students to construct the big picture of CC impacts, but also enables them to gradually zoom into their local environment where place-based approach is activated. It is indicated that the combination of the two approaches raises student awareness and enhances student understanding of the size of natural hazards' impact, through the combined global, local, and diachronic perspective it offers;
3. EO-based educational material and tools stimulate student interest for learning more about satellites and EO and promote their upskilling, especially when they get the chance to interact personally with the relevant applications;
4. The phenomenon-based approach and specifically the dry storm phenomenon grabs teachers' and students' attention, provokes their curiosity, and acts as a springboard for scientific inquiry of climate change impacts such as wildfires;
5. The combined use of EO-based applications and novel pedagogical approaches promotes teachers' upskilling and provokes spontaneous intra-school collaboration. As seen during MaFiSS implementation, ICT teachers collaborated voluntarily with primary school teachers because they got personally interested in learning more about the EO tools used in MaFiSS;
6. Finally, the inherent interdisciplinary nature of the EO-based pedagogical material blends naturally with a lot of topics in the Greek primary school curriculum. It is indicated that teachers utilize these correlations, thus helping students to make sense of concepts taught at school beyond the classroom context.

Based on the above findings, we can conclude that a prerequisite for attracting newcomers to EO in schools is attention-grabbing pedagogical content that sparks interest among teachers and students. Content should also be adaptable to local needs or circumstances, match the school's curriculum, use intuitive EO tools with minimum infrastructure requirements, and be based on modern pedagogical approaches. Such EO-based educational material can act as an entry point for EO in schools that can benefit CCSE and possibly lead teachers and students to seek further deepening of their EO knowledge through EO training programmes or online EO learning platforms.

Undoubtedly, further research is needed for consolidating these initial conclusions from MaFiSS and for quantitively assessing the students' comprehension enhancement of Earth System Science principles through EO. Given that EO has demonstrated its applicability in classrooms despite the demands of everyday school reality [14–16,27], we plan to continue the efforts for developing EO-based programmes that promote CCSE. Our future plans include the development of a follow-up EO-based programme according to the MaFiSS approach, utilizing further EO technological advancements. Specifically, we aim to develop new material based on the ground-breaking technologies implemented for Aeolus, ESA's pioneering EO mission. Aeolus is the first satellite mission to deliver profiles of Earth's winds on a global scale using the most sophisticated doppler wind lidar ever flown in space. Based on lessons learnt from the Aeolus pilot educational programme designed by the authors and implemented on sixth grade students at the Aeolus conference in Rhodes [59], we aim to utilize the MaFiSS approach in order to address thematics related to Meteorology and Atmospheric Composition in Greek schools. Through the implementation of the future Aeolus educational programme in schools, we intend to collect statistically significant quantitative data to appropriately assess the program's impact on student understanding and on environmental behavior change.

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Informed Consent Statement: Not applicable, as this study does not contain personally identifiable information.

Data Availability Statement: Data can be made available by the corresponding author upon request.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Since September 2021, by decision of the Minister of Education, issued on the recommendation of the Institute of Educational Policy (IEP), «Skills Laboratories» were introduced as a mandatory subject in the primary school and secondary curriculum, aiming to enhance the cultivation of soft skills, life skills, technology, and science skills among pupils through interdisciplinary, collaborative, inquiry-based, or project/problem-based educational activities (https://eurydice.eacea.ec.europa.eu/news/greece-21st-century-skills-labs-ergastiria-dexiotiton (accessed on 22 September 2023)). According to IEP's guidelines "Skills Labs" activities, which fall under four broad thematic units (environmental sustainability; health and well-being; citizenship and social behavior; and STEM, robotics, and entrepreneurship), should all be addressed through the school year (two-month period for each topic). For this purpose, one didactic hour per week has been allocated in the schools' timetable of the upper primary and secondary grades and two or three hours in the lower primary school grades.

Appendix B

In Table 1, we present the brief questionnaire given to students at the start of LP-1, which introduces the subject of wildfires and engages students in a small-scale internal investigation of their prior knowledge and experience with wildfires through a set of open-ended and close-ended questions. Some of the close-ended questions are deliberately thought-provoking and others contain surprising elements in the possible answers in order to stimulate student interest for the inquiry-based learning activity that follows, during which students search for the correct answers in the adapted scientific texts provided.

Table A1. Brief questionnaire given to students at the begging of the inquiry-based learning activity of the first Lesson Plan.

Open and Close-Ended Survey Questions	Possible Answers
Q.1 Which of the following conditions help wildfires spread faster?	A.1. Choose as many answers as you think apply: Strong winds/High temperatures/High humidity/Up-hill terrain/Dry vegetation/Down-hill terrain
Q.2. Wildfires are caused either by human actions or by natural phenomena like lightning and volcanoes. What do you think sparks most of the fires in the Mediterranean forests?	A.2. Choose only one answer: Mostly human actions/Mostly natural causes/Both equally
Q.3. What human actions do you know which can cause a wildfire?	A.3. Write what you know
Q.4. In which of the following areas of the world do you think most wildfires occur?	A.4. Choose only one answer: African forest and savannas/Amazon tropical forests/Mediterranean forest/Boreal forests
Q.5. How long do you think wildfires can last in Siberia, Canada, or Alaska?	A.5. Choose only one answer: Hours/Days/Months
Q.6. Global warming is changing the earth's climate and increases weather extremes, which in turn amplify forest fires. Which of the following weather extremes do you think contribute the most to wildfires?	A.6. Choose as many answers as you think apply: Stronger winds/extended heat waves/extreme storms/increased lightning activity/extreme snowstorms/reduced precipitation
Q.7. Have you ever witnessed a wildfire in the past?	A.7. Choose one answer: Yes/No
Q.7.1. If yes, has you, or anyone from your family, been in danger because of that wildfire?	A.7.1. Choose one answer: Yes/No
Q.8. Which catastrophic wildfires in Greece or abroad do you remember?	A.8. Write what you know

The provided scientific texts are designed to help students find the correct answers to the close-ended questions, which are as follows: (a) for Q.1, all apart from "High humidity" and "Down-hill terrain"; (b) for Q.2, "Mostly human actions"; (c) for Q.4, "African forest and savannas"; (d) for Q.5, Months; and (e) for Q.6, all. Results from this questionnaire have been gathered and analyzed but not presented here as it is considered out of the scope of the current paper.

Appendix C

Here, we present some interesting findings based on the analysis of the student worksheets and other student products after MaFiSS implementation.

Appendix C.1 Wildfires Survey Worksheets

According to the answers given by students during the internal wildfires survey undertaken in LP-1 of MaFiSS, the results are as follows: (Number of students 55 = 17 + 16 + 22).

Regarding the conditions that help wildfires spread faster, the majority of the students, as anticipated, chose strong winds (93%), dry vegetation (89%), high temperatures (82%), and down-hill terrain (47%) as the major contributing factors (see Figure A1**)**. However, in E2 Agrinion class, the majority of students almost ignored the terrain as a factor contributing to wildfires (13% chose down-hill terrain and 6% uphill terrain). According to the teachers' feedback and the students' programme evaluation results (see SEQ.15), the terrain factor in the possible answers managed to spark student interest for further investigation and left a lasting impression on them (see Table 3).

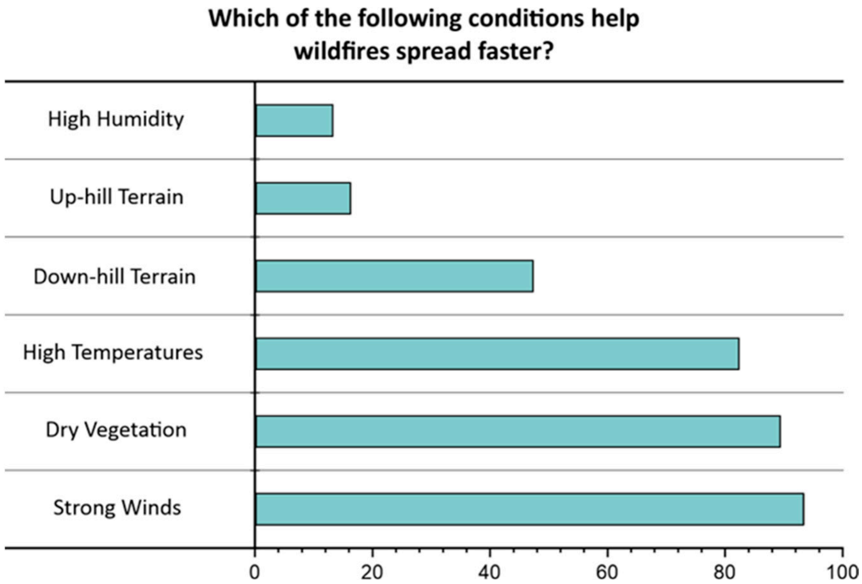

Figure A1. Student answers (n = 52) regarding the conditions that help wildfires spread faster.

As for the causes of wildfires in the Mediterranean forests, although the leading response is "Mostly human actions" by 48%, surprisingly, the percentage of students that think both natural causes and human actions are equally responsible is quite high (45%); 7% think it is "Mostly natural causes" that spark most of the fires in the Mediterranean forests.

When students were subsequently asked to describe which human actions responsible for sparking wildfires they know of, they overwhelmingly designated cigarette butts as the leading cause (80%), followed by litter (36%), arson (35%), and camp fires/outdoor grills by (25%).

Coming to the intentionally puzzling questions aimed to provoke interest for subsequent investigation, such as the areas of the world where most wildfires occur, as expected, students answered that most fires occur in the Mediterranean forests by 42%, followed by the African forests and savannas (22%) and the tropical forests (20%). Similarly, for the duration of wildfires in boreal forests, students, as expected, answered according to their experience (76% answered days, 13% months, and 11% hours). As for the weather extremes that contribute the most to wildfires, students, again, according to their experience, chose "extended heat waves" by 85%, stronger winds by 65%, and reduced precipitation by 36%.

Regarding students' own experience with wildfires, 40% have personally witnessed a wildfire, and of those, 5% have been in actual danger. The remaining 60% have never witnessed a wildfire personally. However, as seen in Figure A2, percentages vary dramatically between Athens and Agrinion classes. Specifically, in E1-Athens class, 59% of students have personally witnessed a wildfire, and of those, 14% have been in actual danger. In contrast, only 27% of students from both Agrinion classes have personally witnessed a wildfire, and none of them have ever been in actual danger. This major difference is well explained by the fact that the Attika region, where the E1-Athens class is located, is one of the areas that is most frequently affected by wildfires in Greece. Additionally, Athenian students quite often spend their summer holidays in nearby summer camps or summer houses their families own.

Finally, as far as wildfires students can recall, 73% seems to remember either the 2018 "Mati" or the 2021 "Northern Evia" wildfires or both. Other wildfires mentioned sporadically alongside the above fires are Ymittos, Anavyssos, Loutraki, Aegio, Xylokastro, Nafplio, and Lefkada fires. An amount of 27% of students could not recall any wildfires.

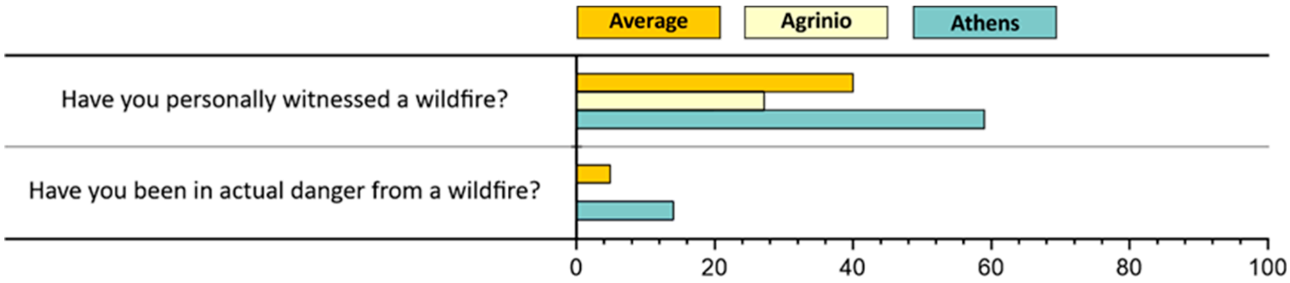

Figure A2. Student responses on their wildfire-related experiences (n = 52)—Comparison between Agrinion and Athens students.

Appendix C.2 Fire Scar Mapping Worksheets

Based on the LP-3 Mati and Kineta fire scar mapping worksheets (see Figure A3), it became evident that this activity challenged students considerably. Although according to teachers' feedback students loved the hands-on nature of the activity, when the mathematical calculations kicked in, quite a few students required a lot of encouragement and help in order to complete the activity. This finding is consistent with the results of the calculations and students' MaFiSS evaluation responses where this activity was rated as one of the least favorites due to the mathematical calculations it required.

As for the actual student calculations, when analyzed, the results showed as expected a much higher mapping accuracy in the case of Kineta compared to Mati. This was an anticipated result considering that in "true color" satellite images, forest fire scars such as Kineta are much easier to distinguish compared to fire scars in residential areas such as Mati. Additionally in the Mati case, students had the extra difficulty of converting units of measurement, which increased the degree of difficulty.

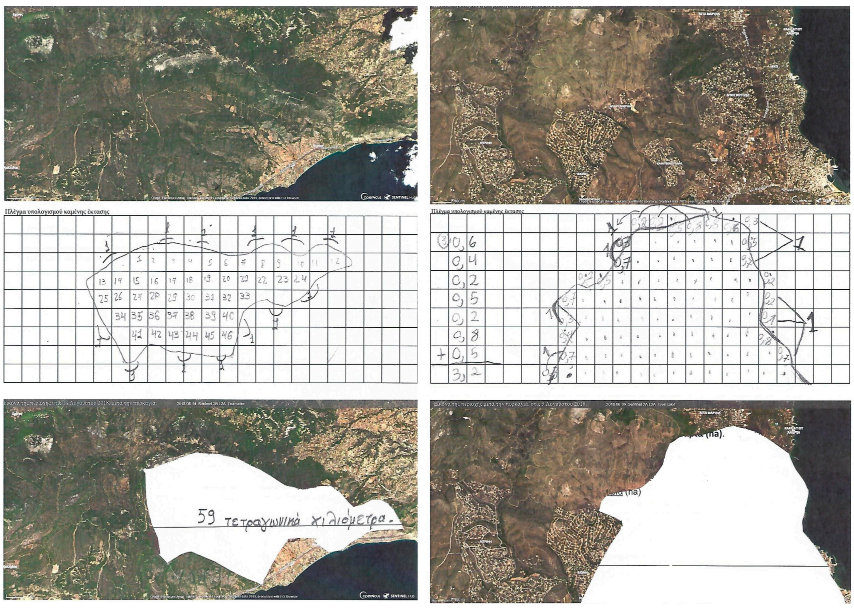

Figure A3. Selected samples of student fire scar mapping worksheets. On the left, the student calculated 59 km2 of burned area in Kineta and on the right student attempted to calculate as accurately as possible the burned area in Mati using decimals.

Appendix C.3 EO Browser Interactions

Students in the two Agrinion classes who had the chance to interact personally with EO browser in the school's ICT lab managed very quickly to become familiar with the application using the written step-by-step instructions available in the scenario's supporting material. Students, within one didactic hour, managed to locate the fire scar of the Northern Evia 2021 forest fire, search and select low cloud coverage before and after fire true-color visualizations, pin selected images, compare pinned images using the split slider, and calculate the burned area using the polygon functions (see Figure 9).

Additionally, prompted by their teachers, certain students embarked on a search for traces of the 2011 local wildfire in the oak forest of the Skourtou Aitoloakaranania region. The EO browser, launched in 2017, yielded no results, leading the students to realize the advanced and recent attributes of this cutting-edge technology. Other students expressed interest in exploring different EO browser themes, such as volcanoes, snow, glacier, and floods, and proceeded to test such themes during the last few minutes of the didactic hour.

In the Athens class, on the other hand, where the EO browser was simply demonstrated and students did not have the chance to interact personally with it, there are no data to report on how quickly and effortlessly students can familiarize themselves with the application. However, we can certainly report that the application intrigued students based on the fact that upon their return to school after the snowstorm "ELPIS" that hit Athens on the 24th of January 2022, they requested to use the EO browser in order to get a satellite post storm view of their city (Figure A4).

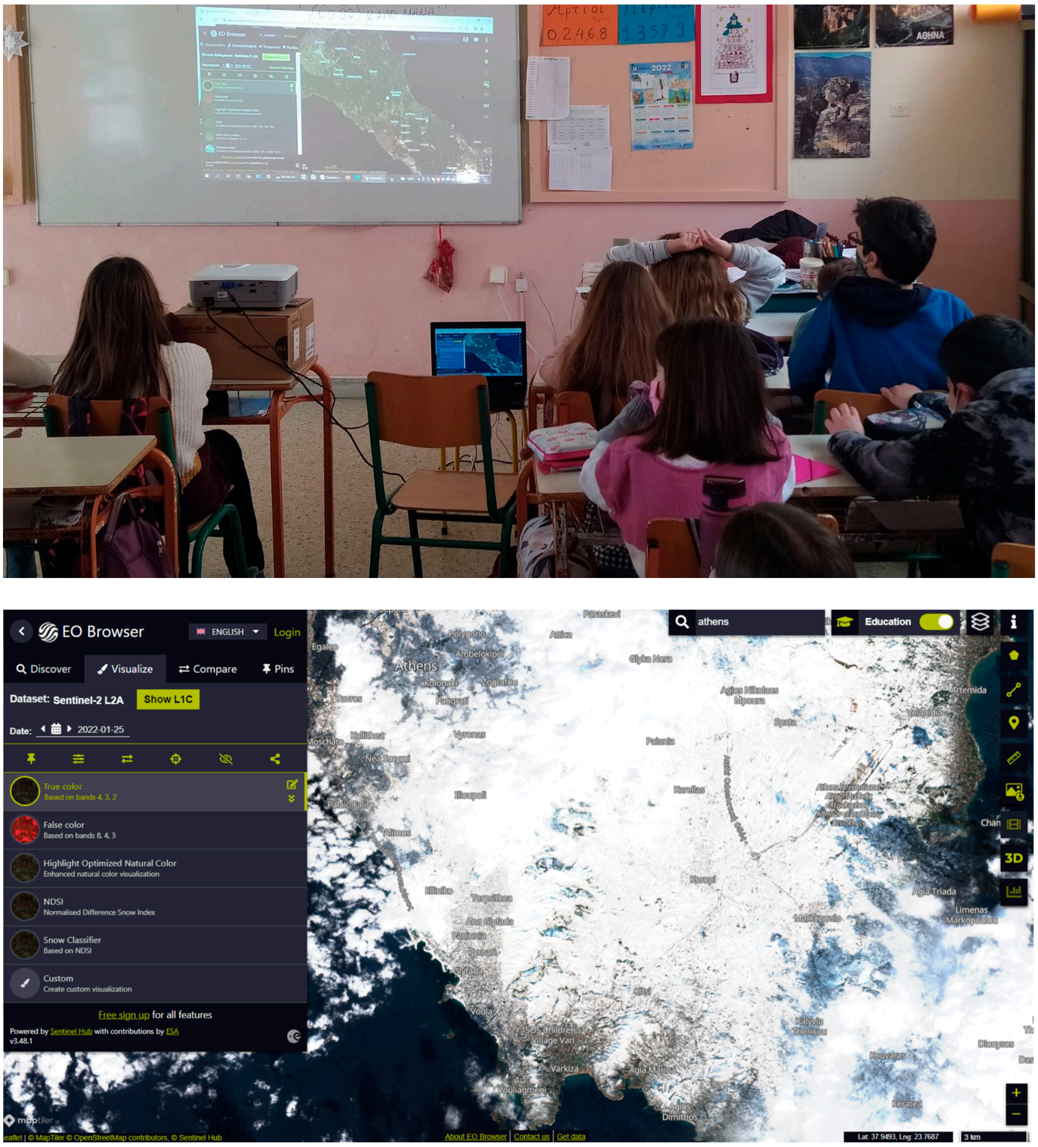

Figure A4. Demonstration of EO browser's functionally by the teacher in the Athens class (**top**) and EO browser image of post snowstorm Athens, retrieved by the Athens class (**bottom**).

Appendix C.4 BEYOND Diachronic BSM Products

Students in all three classes fully utilized BEYOND's Diachronic BSM tool for cataloging all past wildfires in their region. Based on student products and according to teachers' feedback, this activity helped students realize the magnitude of the wildfire problem. It also helped them recognize and critically reflect on its causes and impacts for the local environment and, thus, led them to gain new awareness and a newly found passion for wildfire prevention campaigning.

However, for optimal educational utilization of this tool, teachers noted that an education mode has to be added similar to the one found in the EO browser. This mode should provide: (a) a simplified, user-friendly interface with no popup scientific info windows, (b) a hover function for displaying burned area size, and (c) an option for downloading a selected portion of the displayed map.

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