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Research article

Water and Us: tales and hands-on laboratories to educate about sustainable and nonconflictual water resources management

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Abstract. Climate change and water security are among the grand challenges of the 21st century, but literacy on these matters among high-school students is often unsystematic and/or detached from the real world. This study aims to introduce the educational objectives, methods, and early results of "Water and Us", a three-module initiative that can contribute to advancing water education in a warming climate by focusing on the natural and anthropogenic water cycle, climate change, and emerging water conflicts. The method of Water and Us revolves around storytelling to aid understanding and generate new knowledge, learning by doing, a flipped-classroom environment, and a constant link to examples from the real world (such as ongoing droughts across the world or seeds of conflict regarding transnational river basins). Water and Us was established in 2021–2022 and, during that school year, involved ≥ 200 students as part of a proof of concept to test the complete didactic approach using small-scale experiments. Results from ≥ 40 h of proof-of-concept events confirmed the effectiveness of this approach with respect to conveying the essential elements of the natural and anthropogenic water cycle, the most commonly recurring concepts related to climate change and water as well as the possible conflicts and solutions related to water scarcity in a warming climate. The Water and Us team remains interested in networking with colleagues and potential recipients to upscale and further develop this work.

1 Introduction

Climate change is the big elephant in the room of our times. Fueled by anthropogenic emissions of greenhouse gases, climate change "has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability" (IPCC, 2022). These impacts include an increase in heat waves and extreme precipitation; an increase in human and tree mortality, wildfires, ocean acidification, and sea level rise; damage to ecosystems; and reduced food security (IPCC, 2022). While some steps have been taken since the seminal United Nations Framework Convention on Climate Change in Rio de Janeiro (1992) and attention from the public has increased thanks to initiatives like Fridays for Future, the United Nations Sustainable Development Goals, or the Sendai Framework for Disaster Risk Reduction, "most observed adaptation is fragmented, small in scale, incremental, sector-specific, designed to respond to current impacts or near-term risks, and focused more on planning rather than implementation" (IPCC, 2022). The current consensus, at both the scientific and societal level, is that challenges related to climate change mitigation and adaptation will characterize the world for several generations to come (Hansen et al., 2013; Zhenmin and Espinosa, 2019).

If climate change is the elephant, then the most proximal resource to humans and ecosystems – water – is the floor on which the elephant is standing. A rise in temperature, as predicted by climate change scenarios, will lead to an increase in drought episodes (Spinoni et al., 2018), a rise in extreme events (Alfieri et al., 2017), a decline in snow-

water resources (Mote et al., 2018; Musselman et al., 2021), glacier depletion (Shannon et al., 2019), an imbalance between water demand and availability (Barnett et al., 2005; Immerzeel et al., 2020), and eventual profound alterations to the whole water cycle (IPCC, 2022). Given the extent and intensity of human water management, such changes may ultimately result into societal instability, conflicts, poverty, displacement, and less water security at the global scale (Kelley et al., 2015; Galli et al., 2022). This is particularly true in regions where precipitation is highly seasonal and/or where snow and glaciers play a fundamental role in storing water during wet and cold winters to release it during warm and dry summers (Barnett et al., 2005; Avanzi et al., 2023). Such changes in the water cycle will inevitably challenge our societies, as the water cycle, ecosystems, and human societies are and always will be intimately connected.

Despite these intimate connections, contemporary geosciences and, by reflection, water education from elementary to high schools often remain anchored in a traditional view of the water cycle as a physical process in which humans have little to no role. Meanwhile, surveys from various parts of the world show that students tend to confound mitigation and adaptation to climate change with unrelated environmental issues (Bofferding and Kloser, 2015), while the knowledge gained at school often does not translate in everyday habits (Amahmid et al., 2019) due to current high-school students' environmental literacy possibly being inadequate (Wardani et al., 2018). These experiences speak for a need to expand how climate change education is done (Harker-Schuch and Bugge-Henriksen, 2013), as acknowledged by United Nations Educational, Scientific and Cultural Organization (UNESCO; https://en.unesco.org/themes/water-security/hydrology/water-education, last access: 4 September 2022).

This paper aims to introduce the objective, methods, and early results of "Water and Us", an educational initiative developed by the CIMA Research Foundation (Italy) to encourage scientists and teachers to co-deliver lectures on three topics: the natural and anthropogenic water cycle, climate change, and emerging water conflicts. Thus, the initiative contributes to filling knowledge gaps on the important but often poorly understood link between water resources and security, climate change, and institutional governance. Water and Us is an interdisciplinary initiative bringing together hydrologists, jurists, and communication experts, and it is strongly committed to cross borders within and across scientific fields of study to modernize water education in a warming climate.

The paper is organized as follows: Sect. 2 introduces the educational approach of Water and Us, with particular emphasis on its objectives, their implementation into three modules for high schools, and their counterparts for elementary schools and adults; Sect. 3 discusses an array of metrics that we identify to evaluate this approach in the context of our early results for this initiative; and, finally, Sect. 4 draws conclusions.

2 The educational approach

In describing the current method of Water and Us, we will inevitably refer to our specific experiences in Italy; the reader is referred to the example of storytelling in the Appendix regarding the Alpine 2022 drought. However, the approach described here is fully transferable, with Chap. 4 of the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 on water providing a general framework to identify emerging risks for a given location and how these risks link to governance challenges (see https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Chapter04.pdf, last access: 8 May 2023). The authors have also provided an open, online repository of the materials used (https://doi.org/10.5281/zenodo.8341482; Munerol et al., 2023). The only requirement is for students to have a basic understanding of the water cycle.

The primary target audience of Water and Us is high-school students (these students are 14 to 19 years old in Italy), but the offer has already been adapted for elementary schools and adults. The choice of high-school students was due to two main factors. The first is the clear fit between this initiative and high-school programs in Italy. In this regard, Water and Us directly contributes to civics (Educazione Civica in Italian; see https://www.istruzione.it/educazione_civica/, last access: 13 September 2023), which includes educational targets regarding sustainability and environment awareness, and to science programs, which include chapters on the Earth system, the water cycle, and climate. The second is the symbolic leverage of high schools, as they represent the last step of mandatory education in Italy; this means that high-school students are in the process of deciding their own future when they are exposed to Water and Us, an aspect that promotes engagement and awareness.

The main structure of the initiative revolves around three objectives, four didactic pillars, and three modules (each needing 1.5 to 2 h). Figure 1 summarizes these pillars and the content of each module.

2.1 Objectives

The main educational objectives of Water and Us are as follows:

1. inform next generations with respect to (a) the concept of "water resource" as an intertwined result of the natural water cycle and anthropogenic actions and (b) how, where, when, and by whom water is used, transported, stored, and diverted in the Anthropocene;

2. educate students on the most salient aspects of climate change and its governance, including the difference between mitigation and adaptation, the role of interna-

tional agreements, the scientific foundation of global warming, and how these processes affect water availability at all scales – including future scenarios of water supply, floods, and droughts;

3. raise awareness of existing and potential governance conflicts around the use of water, especially in a warming climate, and of solutions for nonconflictual water resources management.

These objectives are well nested into the Sustainable Development Goals (SDGs), in particular SDG no. 4 ("Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" – Target 4.7 on ensuring that all learners acquire the knowledge and skills needed to promote sustainable development), SDG no. 10 ("Reduce inequality within and among countries" – Target 10.2 on empowering and promoting the social, economic and political inclusion of all), and SDG no. 13 ("Take urgent action to combat climate change and its impacts" – Target 13.1 on strengthening resilience and adaptive capacity to climate-related hazards and natural disasters in all countries).

2.2 Didactic pillars

From a methodological standpoint, Water and Us leans on four overarching pillars (Fig. 1).

The first is an educational approach based on storytelling, under the assumption that the ancestral attraction of humans towards tales will gain participants' attention and enhance understanding. This first pillar goes well beyond "telling anecdotes"; instead, it nests itself in a broad body of empirical and theoretical literature in education showing that storytelling can significantly reduce depersonalization, develop identities, promote empathy and diversity, aid with understanding of complex issues by linking them to the proximal world experienced by students, and ultimately generate new knowledge (Abrahamson, 1998; Collins, 1999; Haigh and Hardy, 2011; Hibbin, 2016; Astiz, 2020). In doing so, Water and Us seconds the advent of digital devices and, thus, digital storytelling to generate vivid experiences for students through the mixture of voices, images, and videos (Robin, 2008). Note that our stories focus on contemporary events, such as ongoing droughts across the world, rather than traditional tales (see the Appendix for an example).

The second pillar encompasses hands-on experiences in order to immediately put theory learned into practice. During our events, for example, students are asked to identify potential water stakeholders in familiar and less familiar landscapes and then to impersonate these stakeholders in focus groups to reflect upon their needs with regard to water and how these needs may conflict with (or be in synergy with) other stakeholders. Groups are finally asked to discuss these findings in an effort to tackle emerging conflicts and maximize synergies (see Sect. 2.3 and 2.5). Thus, we openly link Water and Us to the long-standing educational tradition of "learning by doing" (Schank, 1995) to go beyond the artificial setting of school education and allow for a more natural, immediate understanding of the subject matter.

Learning by doing is connected to the third pillar, which is a flipped-classroom environment in which students become the protagonists of the teaching experience. To this end, each module in Water and Us includes workshops led by the students for the students. In this framework, storytelling introduces the minimum amount of knowledge required by students to conduct the workshops themselves (although lack of preparation is a frequent problem in flipped classrooms; Akçayır and Akçayır, 2018). While relatively new, this flipped-classroom approach has already been widely applied, with proven benefits (Awidi and Paynter, 2019).

The fourth pillar is a constant link to the real world, in particular to the most pressing, contemporary societal issues – water security and climate change. The hypothesis here is that focusing on the real world will make topics covered by Water and Us more tangible and, thus, more interesting to students, as they can directly relate to their future in a changing climate during the 21st century. This is in line with existing literature which shows that climate change education must be accessible and action-oriented (e.g., see Lee et al., 2013). In this regard, Water and Us synthesizes a geoscience-based approach to climate change with policy and governance, in an effort to make this initiative open to all aspects of water in the modern era.

2.3 Module 1: read the waterscape

Starting from the four didactic pillars outlined above, the first module of Water and Us focuses on the water cycle in a warming climate (Fig. 2). This module builds on the premise that water is an essential resource for life on our planet to make three broader points: first, that the natural evaporation–precipitation–runoff water cycle is now part of a much broader and more complex mechanism including regulations, allocations, and demands by human societies, which can significantly change the natural course of water across our planet and introduce a striking variety of water stakeholders (Sivapalan et al., 2012); second, that this natural–anthropogenic water cycle relies on an intermediate natural reservoir – snow – in temperate regions of the world which is often overlooked and rarely seen as a key precondition for life on our planet (Barnett et al., 2005); and, third, that this natural–anthropogenic water cycle is changing, due to a recurring temperate-region pattern of warmer temperatures, less snow, and eventually less available water (IPCC, 2022).

We originally chose to make these points by linking future scenarios of temperature, snow, and water supply in Italy with an exemplary story from another part of the world – the California 2012–2016 snow drought (see Harpold et al., 2017, and the Appendix). By showing the real-world implications of the link between warmer temperatures, less snow, and less water, the California drought is a perfect example of

PILLARS	MODULE 1: READ THE WATERSCAPE	MODULE 2: THE 21st -CENTURY TOOLBOX	MODULE 3: WATER CONFLICTS
STORY-TELLING	Parallelism between the Californian 2012-2016 drought and the Italian 2022 drought		Parallelism between the water crisis in Lake Turkana and in Lake Maggiore + 2022 italian drought
LEARNING BY DOING	Students, gathered in groups, learn how to identify who uses water, how, and why	In groups, students search for the meaning of an assigned list of climate-related words, alongside accredited sources	By role-playing, students work in groups to better understand how stakeholders act based on their needs
FLIPPED CLASSROOM	Students then report their findings to the class	Groups then exchange, discuss, and negotiate definitions and sources	Students, role-playing as the stakeholders, report their water needs and strategic positions to the other groups
REAL WORLD	The Californian and Italian droughts	Climate change, IPCC, Paris Agreement etc.	Lake Turkana & Lake Maggiore, water conflicts
MAIN POINTS	-warmer temperatures cause changes in the water cycle -humans affect the water cycle -snow as a key reservoir	-we need an accurate vocabulary to describe 21st-century climate challenges -to master it means getting the chance to make an impact	-water conflicts exist and may be exacerbated in the future -new generations can be part of climate solutions

HOW THE 4 DIDACTIC PILLARS COME INTO PLAY IN WATER AND US

Figure 1. The four overarching pillars of Water and Us (first column) and how they come into play in the three educational modules.

Figure 2. Some content from Module 1 of Water and Us: students learning how to read the waterscape (who is using water, where, and why?) and an iconic image of the California snow drought (then Governor Jerry Brown taking part in the 2015 Snow Survey at Phillips Station, the first with no snow on the ground in April; image credit: CA Department of Water Resources).

the challenges posed by global warming and increased aridity for the natural–anthropogenic water cycle that we experience.

Our events started in January 2022; therefore, we soon had to readapt the framework to include the unfolding Italian drought (see the Appendix). We made the pragmatic choice to retain the California story, but we progressively included parallels to the 2022 Italian temperature and precipitation anomalies, snow deficit, and streamflow lows. We found that doing so enhanced credibility of our stories, as students appreciated patterns across continents and were able to find links to topics that were covered by the media and social networks at the time. Albeit unfortunate in nature, this coincidence of events made Water and Us concrete and relevant to students.

The focus on droughts was instrumental, as it allowed us to link Water and Us to our own experiences related to climate change and water and, thus, make communication more effective for our audience. We acknowledge that other water risks may be relevant with respect to different contexts, cultures, and representations of what is at stake, such as sea level rise (Cazenave et al., 2014), emerging flood pressure (Hirabayashi et al., 2013), shrinking glaciers endangering mountain communities (Council et al., 2012), or increasing desertification (Stringer et al., 2009). Even while maintaining a focus on droughts, other episodes can be useful to contextualize local events in a global framework, such as the multiyear drought in the Andes (Rivera et al., 2017) or in Australia (Saft et al., 2015). The key ingredient of this first module is the focus on nature–human interactions around the use of water and on how these interactions are challenged in a warming climate.

The first module always ends with a workshop that is dedicated to putting gained knowledge about the natural–anthropogenic water cycle into practice. We gather students into small groups (maximum of four to five members), assign one landscape to each of them (examples are given in Fig. 2 and in our online repository at https://doi.org/10.5281/zenodo.8341482; Munerol et al., 2023), and ask students to pinpoint who is using water, how, and why; thus, students train themselves to read the waterscape. Students are left with approximately 15 min to accomplish this goal and are asked to write their notes on sticky notes that are then placed on their waterscapes. At the end of this work, students report their findings to the class and come up with a bottom-up, shared categorization of recurring water stakeholders (see Sect. 3). We found this to be particularly important, not only because knowledge of water stakeholders is a precondition to understand the following modules in Water and Us (and more generally what is at stake regarding water security in a warming climate; see Sect. 2.5) but also because most high-school students that we interacted with reported that the last time they were taught about the water cycle was in elementary school.

2.4 Module 2: the 21st-century toolbox

The second module focuses on climate change, a term that is well known to students but that – often – few are able to clearly explain. This gives us an opportunity to convey two main messages: 21st-century challenges have a precise and accurate vocabulary and handling this vocabulary is a precondition for next generations to play an impactful role in shaping the future. At the same time, information that can be gathered from current media can be inaccurate or simply partial. This second module of Water and Us aims to go from such incomplete definitions to a coherent picture of the ongoing climate change debate at the global scale.

Different from modules 1 and 3, Module 2 is entirely based on a workshop (Fig. 3). Students are again shuffled into small groups and are assigned a list of terms related to climate change, namely, “global warming”, “IPCC”, “COP”, “sustainability”, “greenhouse gases”, “mitigation and adaptation”, “extremes”, “drought”, “floods”, and “Paris Agreement”. We then ask students to use their own knowledge and digital devices to come up with an accurate, and yet concise, definition of each of these terms. While doing so, we ask them to check for multiple sources, note down these sources, and discuss how and why definitions may differ across them. After this first round, each group of students is asked to explain their definition to the class, not only to improve shared knowledge but also to potentially compare definitions across groups and, thus, realize the quality of accredited and independent sources.

This workshop can be iterative, based on available time and feedback from students; for example, we often notice a particular interest from students in the IPCC and, therefore, conduct a second round using words like “RCP”, “climate”, or “future scenarios” to encourage their interest in this sense. At the end of the workshop, we encourage students to note down the final definitions and keep them as a toolbox for future use.

2.5 Module 3: water conflicts

Module 3 connects the dots between the previous two modules and focuses on the main societal implication of a changing climate in a natural–anthropogenic water cycle: emerging water conflicts.

Discussing water conflicts with Italian students may be challenging, as they tend to associate these matters with more arid regions of the world. To overcome this issue, we break down our story into two parts. The first is indeed quite exotic for our audiences and deals with the water crisis concerning Lake Turkana and how it is associated with climate variability (Yongo et al., 2010). For our audience, this has the classical setting of water crises as they expect them. We then move to a lesser-known situation: the transnational management of Lake Maggiore across Italy and Switzerland and how it is exacerbated by ongoing climatic extremes (Guariso

Figure 3. Some content from Module 2 of Water and Us: students proposing definitions of the most commonly recurring terms related to climate change.

et al., 1985). We show how national resolutions on the lake level have already led to court decisions or tensions among stakeholders as well as how these tensions are indeed seeds of potential future water conflict. Here, again, the mounting 2022 Italian drought gave us an unfortunate opportunity to bring newspapers and media coverage to classes and discuss concrete examples of these seeds, such as public conversations regarding who was the priority water user or how and when to divert water from one river to another for drought relief.

We end Module 3 with a role-playing game: each group of students chooses one water stakeholders category from those that were identified during Module 1 (with the most commonly recurring categories being farmers, industries, civil water supply, ecosystem conservation, hydropower, and tourism; see Sect. 3). Each group is first asked to reflect on their specific need concerning water (e.g., "When and where do we need water?" "Why do we need it?") and on what decisions they would like society to make in their own interest (e.g., some stakeholders may want little to no water restriction, whereas other stakeholders may be in favor of specific water infrastructure). After reporting these needs and positions to the other groups, they gather again to identify the strategic positions they could take to achieve their needs and establish what positions may, instead, represent a seed of conflict (e.g., some economic sectors may second ecosystem conservation but may dislike priority allocation to other sectors, and so forth; Fig. 4). This workshop ends by summarizing potential conflicts and synergies on a poster (see Fig. 4 and Sect. 3); this poster then remains in the classroom as another deliverable of Water and Us, in addition to the waterscapes and the climate change vocabulary discussed in the previous sections.

2.6 Elementary students and adults

Adapting Water and Us to elementary schools (students 6–11 years old) required rethinking the structure and content of the program to identify a set of messages that were both effective to communicate to children and in line with the overall concept of this initiative. Thus, we selected three core messages related to the importance of water sustainability: first, water is the most precious resource on Earth, as we all need it to live; second, water must be preserved and not wasted; and third, we are not the only ones who need water.

From a methodological standpoint, the elementary edition of Water and Us consists of one, approximately 2 h module. We start with brainstorming session involving the following three questions:

1. Where does water live?
2. What do we need water for?

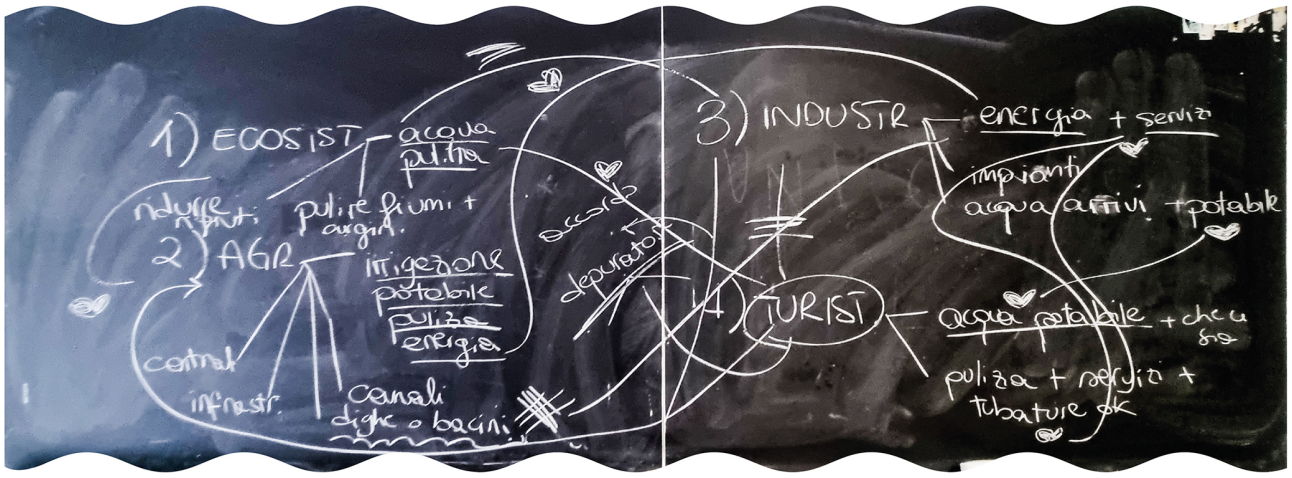

Figure 4. Some content from Module 3 of Water and Us: a map of water stakeholders (e.g., industries, ecosystems services, agriculture, and tourism) and potential synergy and competition.

3. Who uses water?

The answers to these questions are noted on the blackboard and remain visible throughout the event, as they will be used in a third step to reorganize students' knowledge of the natural and anthropogenic water cycle (Fig. 5).

The second step involves telling a story to students while they look at iconic images drawn in color on large cardboard sheets (see Fig. 5). The story is about a child who becomes friends with water and progresses through the typical "ups and downs" of a childhood relationship: they initially enjoy playing together but soon start to play pranks on each other (e.g., the child wastes or pollutes water, while water takes revenge via flooding). At the end of the story, the children become aware that water is their closest friend and that it follows them in all aspects of their everyday life. The concept, structure, and development of the story are all geared towards getting students to relate to the story while also seeing parallels with their daily friendships. This story is available on our online repository at https://doi.org/10.5281/zenodo.8341482 (Munerol et al., 2023).

The final step is to involve students in a drawing workshop: they represent situations in which they have been friends with water and, on the other side of the sheet, situations in which they have been enemies with water. In doing so, we stimulate causal discussions to get feedback and reinforce their learning of core messages.

Adapting Water and Us for use with adults is still a work in progress. To date, our main experience has been with traditional seminars or lectures to professionals or philanthropic organizations about water, climate change, and conflicts. Despite being more conventional in structure and development, we do preserve the central role of storytelling for adults. Here, again, our experience is that starting off using real-world stories, such as the California drought or Lake Turkana, is an effective way of conveying upper-level concepts like climate change and sustainability.

3 Pathway to impact

Water and Us was established in autumn 2021 and worked as a proof of concept during the 2021–2022 school year. The goal of this first phase was to develop the main portfolio of activities, to test it in the real world using small-scale experiments, and to leverage these experiences to identify indicators to validate the method and capture its impact. This phase involved 3 schools, $\geq$ 200 students and 100 adults, and $\geq$ 40 h of events. In this section, we elaborate on these experiences and how they informed an array of proposed indicators (see Table 1).

Regarding Objective no. 1 ("inform next generations on the concept of 'water resource', as an intertwined result of the natural water cycle and anthropogenic actions, and on how, where, when, and by whom water is used, transported, stored, and diverted in the Anthropocene"), we propose using the average and variance of the number of water stakeholders identified on these waterscapes across groups as a concrete measure of the effectiveness of Module 1 in communicating the complexity of the anthropogenic water cycle in the modern era. The average and variance of the number of temporal aspects that each group was able to attach to stakeholders (e.g., "When do they need water?") could also be used to further shed light not only on water users but also on how their needs intersect with each other in time.

In this regard, Table 2 summarizes the main stakeholders identified by students during our small-scale experiments and their frequency of identification (this frequency is expressed in qualitative terms owing to the small number of experiments performed so far). Across all students, the most frequent stakeholders identified on waterscapes were farm-

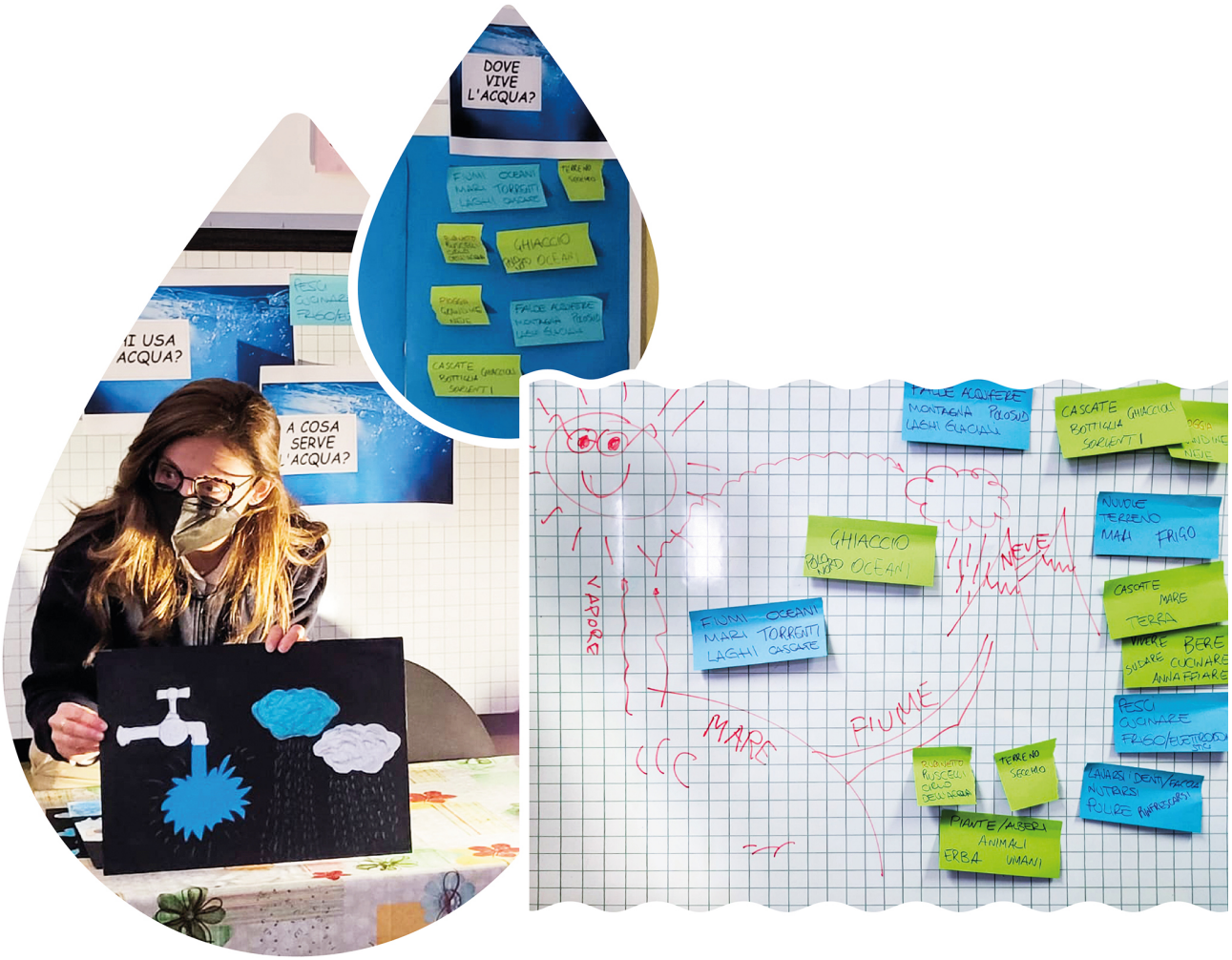

Figure 5. Snapshot from the elementary-school edition of Water and Us, where students are engaged via a dramatization involving a fictional friendship between a child and water.

ers, civil water supply, and industries, in line with most of the involved classes being located in Liguria (Italy), a region with a mixture of cities and rural areas. Hydropower and tourism were less frequently identified as water stakeholders, despite the latter being a key economical sector in Liguria. Across all stakeholders, ecosystems were the least frequently identified on our waterscapes. While frequency of identification will likely change with a larger sample size and will generally depend on local knowledge and the experience of students, the fact that this stakeholder list concurs with that compiled by experts in the field is a promising result with respect to the effectiveness of Water and Us to accomplish Objective no. 1 (e.g., see the latest US Geological Survey water cycle diagram at https://www.usgs.gov/special-topics/water-science-school/science/water-cycle-diagrams, last access: 26 August 2023).

To measure indicators of Objective no. 2 ("educate students on the most salient aspects of climate change and its governance, including the difference between mitigation and adaptation, the role of international agreements, the scientific foundation of global warming, and how these processes can affect water availability at all scales – including future scenarios of water supply, floods, and droughts"), we propose submitting an informal questionnaire to students to gauge their prior and a posteriori awareness with respect to climate change (see some examples in Table 1). Regarding a posteriori awareness, the relative frequency of keywords used by students in Module 2 during 2021–2022 does show salient expressions related to this topic, including "climate change", "greenhouse gases", "emissions", "temperature", and "impacts" (Fig. 6). Interestingly, students also used several policy-oriented words, such as "countries", "agreement", "security", "parties", "scenarios", and "conflicts". We propose explicitly monitoring the prior and a posteriori knowledge of terms emerged in Fig. 6 via a questionnaire as an indicator of students' awareness of the (often cum-

Table 1. Proposed set of indicators to measure the impact of Water and Us. PCTO represents "Paths towards Cross-cutting Skills and Orientation" (Percorsi per le Competenze Trasversali e per l'Orientamento in Italian; see Sect. 3).

Objective	Indicator	Monitoring method
Objective no. 1	Average/variance of the no. of water stakeholders identified on waterscapes	Sticky notes
	Average/variance of the no. of identified seasonal data for water stakeholders on waterscapes	Sticky notes
Objective no. 2	Average/variance of the no. of students with pre/post-awareness of climate change	Questionnaire
	Average/variance of the no. of students with pre/post-awareness of the IPCC	Questionnaire
	Average/variance of the no. of students with pre/post-awareness of the Paris Agreement	Questionnaire
Objective no. 3	Average/variance of the no. of identified synergies across water stakeholders	Sticky notes
	Average/variance of the no. of identified conflicts across water stakeholders	Sticky notes
	Average/variance of the no. of identified "collaborators" across water stakeholders	Sticky notes
General impact	No. of students involved	Organizers' data record
	No. of teachers involved	Organizers' data record
	No. of schools	Organizers' data record
	No. of hours	Organizers' data record
	Percentage of audience in elementary schools	Organizers' data record
	Percentage of audience in high schools	Organizers' data record
	Percentage of audience in non-student positions	Organizers' data record
	Percentage of students taking part in all workshops	Organizers' data record
	No. of schools per year requesting new editions of Water and Us	Organizers' data record
	No. of schools per year requesting follow-up editions of Water and Us	Organizers' data record
	No. of PCTO programs associated with Water and Us	Organizers' data record
	No. of career-related follow-up questions by students	Organizers' data record

Table 2. Main water stakeholders identified by students during our small-scale experiments and their qualitative frequency of identification.

Stakeholder	Frequency of identification (qualitative)	Comment
Farmers	High	This category includes agriculture and breeding farms
Civil water supply	High	–
Industries	High	–
Hydropower	Medium	–
Tourism	Medium	Driven by both summer (beach resorts) and winter (ski resorts)
Ecosystems	Low	–

bersome) decision-making process characterizing adaptation and mitigation to climate change.

Achieving Objective no. 3 represents the essential outcome of the whole process ("raise awareness of existing and potential governance conflicts around the use of water, especially in a warming climate, and of solutions for a non-conflictual water resources management."). Here, again, the hands-on workshop provides concrete indicators to measure this gained awareness: we propose quantification via the average/variance of the number of identified synergies, conflicts, and "collaborators" across water stakeholders – as they emerged across groups. Comparison across geographic locations as Water and Us progresses will allow us to draw a clear picture of how the tendency toward synergies or conflicts changes with time and space, especially as extremes emerge in a warming climate.

During our small-scale experiments in Liguria (Italy), two classes of potential conflicts emerged: the concurrent need for water (possibly different between summer and winter) and water quality preservation (Table 3). According to the involved students in Mediterranean Italy, all water stakeholders can be in conflict with respect to the need for water in summer, with some recurring patterns such as freshwater supply for residents vs. tourists or irrigation water requirements vs. energy production. In our winters, the main source of conflict, according to students, is again centered around the concurrent need for water with respect to residents vs. tourists (or tourist facilities in general, such as ski resorts). As for water quality, this is generally perceived to be an "ecosystems vs. all" example of conflict due to the often elusive understanding of ecosystem preservation by the general public. The fact that students were able to spell out potential concrete conflicts regarding the use of water, along with a fairly extensive list of potential solutions (Table 3), speaks for the promising effectiveness of Module 3 with respect to achieving Objective 3.

We finally propose a set of monitoring indicators to measure the overall impact of Water and Us in terms of the stu-

Figure 6. Relative frequency of keywords used by students in Module 2 (word cloud obtained using https://www.freewordcloudgenerator.com/, last access: 27 August 2023).

Table 3. Preliminary list of the most commonly recurring classes of conflicts and solutions identified in Module 3.

Potential conflict	Stakeholders involved	Potential synergies or solutions
Concurrent need for water (summer)	All	Improve irrigation efficiency Schedule day vs. night shifts Sustainable tourism on farms and in ecosystems Improve distribution efficiency Incentivize small hydro Incentivize water-saving technologies Improve touristic value of hydro reservoirs Improve water reuse
Concurrent need for water (winter)	Civil water supply vs. tourism (especially in mountains)	Improve distribution efficiency Improve snow-making efficiency Incentivize water reuse Incentivize water-saving technologies
Water-quality preservation	Ecosystems vs. all	Improve sanitation efficiency Improve sanitation technologies Raise awareness of ecosystem services Encourage preservation by locals

dents, teachers, and schools as well as the ages of the participants involved (see Table 1). We also propose monitoring the number of students who take part in all modules and the number of schools asking for repeated occurrences of Water and Us throughout the school years as further measures of the impact of this program across years and across modules. As Water and Us also represents an opportunity for students to be exposed to the job market through the concrete topics discussed in the workshops, we finally propose the inclusion of the following additional indicators: the number of career-related follow-up questions by students and, importantly, the number of schools that officially included Water and Us in their career-preparation portfolio. This was the case for one of our high-school events, which was contextualized in the so-called "Paths towards Cross-cutting Skills and Orientation" (Percorsi per le Competenze Trasversali e per l'Orientamento, PCTO, in Italian). Established at national level by Law 145/2018, PCTO projects promote the development of soft and career-oriented skills in high-school students by exposing them to the job market in controlled environments. This framework did not modify the ambition nor the overall organization and spirit of Water and Us, but it concurrently provided us with the opportunity to explicitly

Figure 7. High-school students visiting the CIMA Research Foundation to learn about floods during one of our Water and Us initiatives. This was an opportunity to discuss employability in climate change science as part of "Paths towards Cross-cutting Skills and Orientation" (PCTO; see main text for details).

discuss job opportunities related to climate change and science with the students (Fig. 7).

Water and Us continued in 2022–2023, nested in several national and European projects dedicated to climate change awareness and communication. A concrete example in this regard is the I-CHANGE project (https://ichange-project.eu/, last access: 6 September 2022), in which Water and Us was part of the educational activities related to the Living Lab paradigm in Genoa (https://ichange-project.eu/open-air-laboratory-in-genoa/, last access: 6 September 2022). Regarding future steps, we remain interested in networking with interested partners to upscale this experience to the international level. This will require ways to adapt Water and Us to different audiences and cultures. We identified three promising resources and one precondition to doing so. The first resource is the previously mentioned Chap. 4 of the IPCC Assessment Report 6 on water (see Sect. 2). The second resource is the framework provided by UN-Water (https://www.unwater.org/, last access: 20 May 2023), including its section on water facts that gives concrete examples of water sustainability cases across the globe. The third resource is the UN SDGs (https://sdgs.un.org/goals, last access: 20 May 2023), which also provide concrete examples of targets and metrics related to sustainability and climate change.

The main precondition to upscaling and transferring Water and Us is that these new editions should be collaboratively led by local scientists, rather than the present authors. This is important to maintain one of the most promising aspects of the Water and Us storytelling and overall educational framework: it is about local students engaging with local scientists.

The present authors remain available to accompany and support interested colleagues in this process.

Through Water and Us, we also further aim to advance concrete tools that enable students to make their voices heard with respect to climate change policy. This is important to improve the bottom-up aspect of this initiative and, thus, allow students to inform our work as researchers in hydrology, policy, and governance. In order to achieve this goal, we are experimenting with a fourth module of Water and Us in which students propose concrete measures to tackle climate change, cluster in advocacy groups to promote their vision, and finally vote on each of these propositions (see https://www.cimafoundation.org/en/news/the-next-generation-cop/, last access: 27 August 2023).

4 Conclusions

We presented Water and Us, an awareness initiative contributing to educating the next generations with respect to the challenges of water security and water conflicts in a warming climate. Water and Us was established in 2021 and involved about 200 students and 100 adults across 40 h of events in a first set of experiments in 3 schools to test and validate the approach. We defined a repeatable structure for high schools that was made of three educational modules dedicated to the water cycle, climate change, and water conflicts. Water and Us affirms the value of storytelling and of learning by doing while also putting students at the center of a learning process comprised of hands-on workshops. We continued the experience of Water and Us in 2022–2023, as part of EU Horizon projects geared towards behavioral change and education.

Appendix A: An example of storytelling – a tale of water and snow

Winter 2021–2022 hit the ground running in Italy, with the first snowflakes falling across the Alps in early November. Snow returned between November and early December, when a second large storm hit most Italian mountain ranges. Early snowfalls peaked on 8 December, when snow reached sea level and covered many of our cities (thoughtfully doing so during a national holiday rather than on a busy workday!). After two winters of lockdown due to the COVID-19 pandemic, Italians were finally enjoying snow at its best.

Unfortunately, the season did not proceed as we hoped, and this wet start gave way to a prolonged, and similarly unusual, dry and warm period. Due to a persistent barrier of warm air on the western Mediterranean Sea (meteorologists call it a high-pressure ridge), almost no precipitation fell in northwestern Italy between mid-December and March, with only a couple of short storms in mid-February and mid-March providing limited relief. Meanwhile, warm, strong wind coming down off the Alps caused unseasonably high temperatures and largely melted the mountain snowpack. By the end of March, snow levels on the Italian Alps were 60 % lower than the average of the previous 12 years (2010–2021; Fig. A1; https://edo.jrc.ec.europa.eu/documents/news/GDO-EDODroughtNews202203_Northern_Italy.pdf, last access: 4 September 2022). Water use is at its minimum during winter, so many Italians did not quite realize what was going on nor, importantly, what was about to unfold.

Spring and summer came like a wake-up call. Early loss of snow and the lack of rain quickly led to some of the lowest streamflow levels in recent history across the agricultural and industrial plains of the Po River (Fig. A1). The river, a constant presence that many Italians respect and sometimes even fear during floods, was now just a slow, faint trickle, barely reaching its own outlet into the Adriatic Sea. Meanwhile, newspapers started using a word that many Italians were not prepared to hear, or handle: *drought*. With media coverage also came uncertainty and puzzlement, given how few of us were familiar with this creeping disaster. Many were asking the following questions: “What happened to all that snow we started off with?”, “What are we supposed to do now?”, and “How long will it last?”.

Then came emergency measures, like reducing irrigation water and releasing stored water from Alpine lakes (https://www.adbpo.it/misure-definite-dallosservatorio-per-far-fronte-alla-crisi-idrica/, last access: 4 September 2022). In a country with a fragmented history stretching millennia, these measures exacerbated endemic issues around who has the right to use water first and why. In our Mediterranean climate, the bulk of precipitation occurs during the fall to spring period, meaning that drought conditions are likely to linger at least across summer and early fall. Hence, we are now, in early July 2022, in somewhat uncharted waters, facing at least a few more months of drought (https://edo.jrc.ec.europa.eu/documents/news/GDO-EDODroughtNews202208_Europe.pdf, last access: 14 September 2022).

Nevertheless, what seems like uncharted waters for Italians is a vivid and growing reality in another part of the world. Between 2012 and 2016, California experienced a similarly intense snow and precipitation drought, caused by a high-pressure ridge sending storms north towards the Pacific Northwest rather than the Golden State (Californians called it the “Ridiculously Resilient Ridge”). Drought and low-snow conditions returned to the state in 2020 and show no signs of relenting – a new normal for the US’s largest economy (https://www.gov.ca.gov/2021/04/21/governor-newsom-takes-action-to-respond-to-drought-conditions/, last access: 4 September 2022). The full effects of the current dry period will not be known for years, but these certainly include a spike in tree mortality, a rise in wildfires, and expectedly severe water deficits. Events escalated in 2015, when the then governor – Jerry Brown – issued an executive order mandating a 25 % reduction in water consumption across the state. As allocations across farmers, municipal users, ecosystems, and industries were becoming

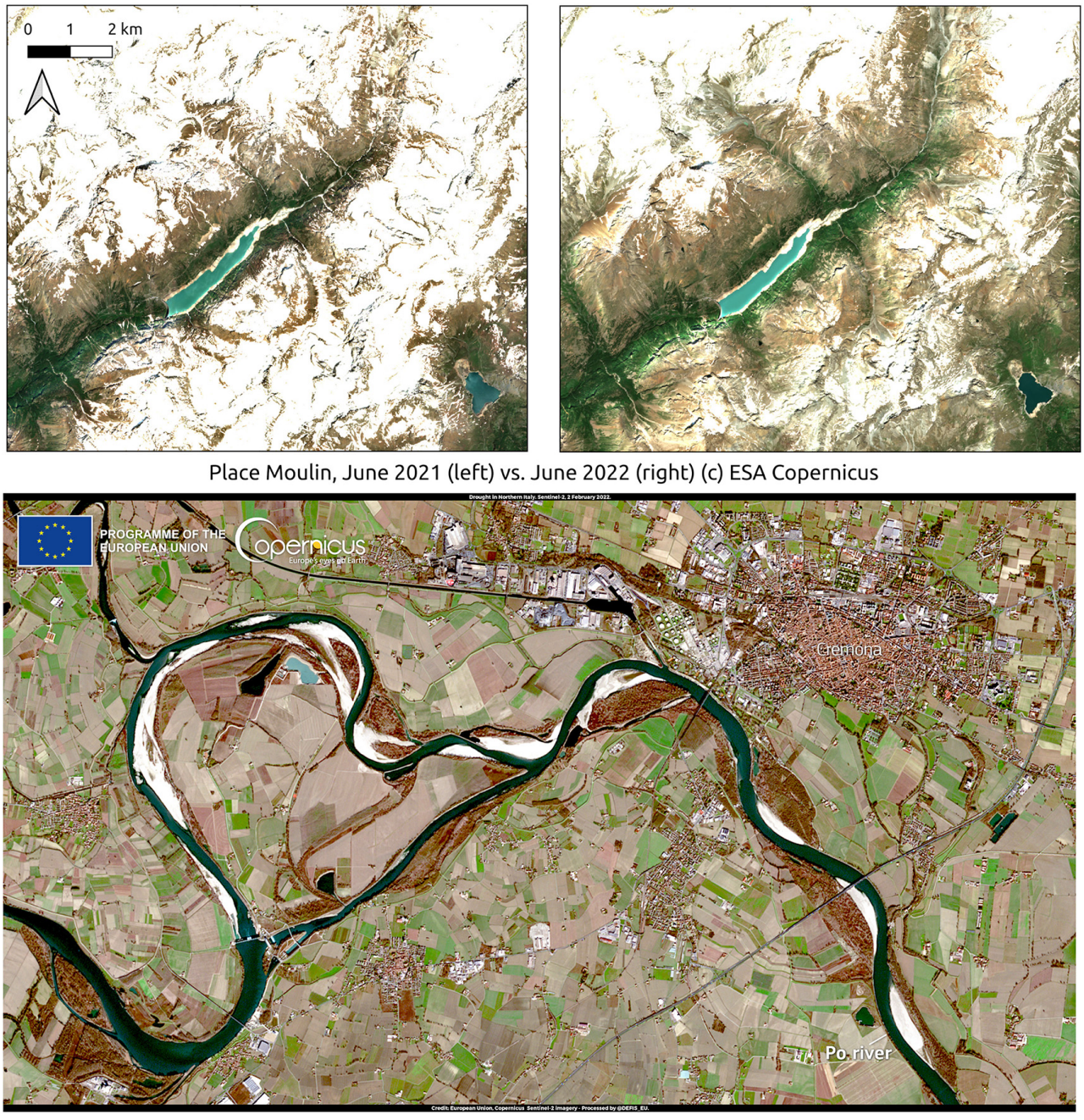

Figure A1. Two key features of the 2022 Italian drought: a marked snow cover deficit (upper panel, Place Moulin in Aosta Valley, June 2021 vs. 2022) and low streamflow (lower panel, Po River at Cremona) (image credit: European Union, Copernicus Sentinel-2 imagery).

increasingly contentious, California also passed landmark laws like the Sustainable Groundwater Management Act to protect groundwater from future non-sustainable use.

What California learned during the 2012–2016 drought is the same lesson that Italy is now learning the hard way – one that will characterize the whole 21st century: warmer temperatures (and occasionally less precipitation) could lead to less snow, less water, and ultimately more conflicts.

Data availability. An online repository of materials used in these workshops is available at https://doi.org/10.5281/zenodo.8341482 (Munerol et al., 2023).

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puts from all coauthors. FM and FA prepared the first draft of this manuscript, with contributions from all coauthors.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Ethical statement. The work presented is original, reflects the authors' observations, and does not deal with sensitive data. The work presented respects what was stated in the Helsinki Declaration of 1964, the cornerstone of the ethics of human research. Ethical approval was requested and obtained from the body to which the authors belong.

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