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A snapshot sample on how COVID-19 impacted and holds up a mirror to European water education

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Abstract. COVID-19 caused many disruptions, not only in society, but also in university education, including in hydrology and water-related sciences. Taking part in an academic teaching training course at Uppsala University during COVID-19, we got curious about how COVID-19 might have impacted European water education. Consequently, we chose to investigate this aspect in the mandatory project of the course by conducting an online survey. In this paper, we communicate the results of the survey and reflect (hold up a mirror to water education) on how the teaching of hydrology and water-related sciences changed due to COVID-19. The answers of 28 respondents, working in the field of hydrology at different universities across Europe, showed that in the pre-COVID-19 classroom lectures, laboratory work and fieldwork were commonly used teaching formats in courses with 10 to more than 40 students. These results agreed with those found in the literature. The occurrence of COVID-19 forced hydrological education to suddenly move from classroom to online teaching, which was possible thanks to the available digital tools and technical infrastructure. The practiced online teaching format remained lectures. Most of the respondents ($> 40\,\%$) reported not using classroom assessment techniques to gauge the students' performances. In addition, a loss of human interaction in the online environment was noticeable. Hence, whether students reached their learning outcomes during distance teaching was largely unknown. The most affected learning activities were the ones that could not be moved to online teaching, such as laboratory work and fieldwork. As a result, comprehensive hydrological knowledge might be missing for at least several cohorts of hydrologists. In this way, COVID-19 caused a secondary effect on society which needs skills in solving future challenges such as water management in a changing climate. Next to negative aspects, we observed positive COVID-19 aspects; for example, the hydrology community explored novel teaching formats and shared teaching material and experiences online. COVID-19 forced hydrology teachers to explore, improvise, and be creative to continue teaching. Hydrology can use this experience to learn from and modernize hydrology education by developing a lesson design suited for the online environment, including best practices and making practical and "exotic" non-traditional teaching formats accessible to all hydrology and water students.

1 Introduction

Hydrology and water-related sciences cover, among other things, water engineering, hydraulics, hydropower, groundwater engineering, water supply and water treatment, hydrogeology, fluid mechanics, ecology, biology, and social science. Hydrology and water-related sciences study the occurrence, circulation, and distribution of water for sustainable use in a changing climate (Foley et al., 2011; Beven, 2016; Blöschl et al., 2012; Seibert et al., 2013). To address these current and future water-related challenges, university water education is fundamental (Wagener et al., 2012).

The university education system we know today evolved over centuries and adjusted its pedagogical approaches from focusing on a few elite scholars to the current massive market-driven integrated learning with student mobility across Europe and the world (Forest and Altbach, 2006).

Water-related sciences are generally considered applied sciences and are taught to a student audience with different educational backgrounds (e.g. engineering, natural or social science) in different departments and institutions (e.g. engineering, biology, geology, environmental science, or geography), each with a variety of educational foci (Gleeson et al., 2012; Seibert et al., 2013; Wagener et al., 2012). The special issue "Hydrology education in a changing world" (Seibert et al., 2013) showcased in 28 papers the variety of hydrology education and different pedagogical approaches up to the year 2012. The pedagogical approaches ranged from teaching and learning activities using physical models in classrooms (Rodhe, 2012), teaching hydrological modeling (Seibert and Vis, 2012a), and learning theoretical physical processes complemented with experimental work in the laboratory and field (Gleeson et al., 2012; Lyon et al., 2013). In addition, general aspects such as the implementation of interdisciplinary curricula (Blöschl et al., 2012), transboundary socioeconomic water issues (Douven et al., 2012), and different levels from education at the secondary school level (Reinfried et al., 2012) to post-graduate education and continued learning for practitioners (Kaspersma et al., 2012) should be addressed.

Contemporary water education has a high complexity, involves multidisciplinary topics (Wagener et al., 2012), and uses specific terminology and definitions (Venhuizen et al., 2019). Hence, it requires a broad educational approach as well as continuous professional development of engineers and water professionals with diverse backgrounds (Popescu et al., 2012; Wagener et al., 2012). Students require strong skills in basic subjects like mathematics, physics, chemistry, soil science, ecology, and social sciences, which should be taught in well-structured courses indicating the connections across disciplines (Wagener et al., 2012; Seibert et al., 2013). According to Seibert et al. (2013), the teaching methods should be

> "rooted in the scientific and quantitative understanding of hydrologic processes, providing flexible hydrologic problem-solving skills that can evolve when new insights become available, and which can be adapted to provide solutions for new problems and to understand new phenomena."

Seibert et al. (2013) suggest that the educational system of hydrology must undergo a paradigm shift away from the current practice. The authors recognize that the current needs of hydrologists to account for e.g. global and local environmental change do not necessarily match the training. In water education, new skill sets should be included to read, interpret, and learn from data and patterns in the landscape, conduct comparative studies to supplement learning through case studies, and understand the spatiotemporally varying characteristics of hydrological systems and the modeling of interacting processes such as human–nature interactions and feedbacks.

University education traditionally took place in classroom environments (French and Kennedy, 2017), and only more recently have novel teaching methods been widely explored. Classroom assessment techniques (CATs) are useful tools (e.g. exit ticket, polls, quizzes, muddiest point, peer review using analogue (e.g. a piece of paper) or digital tools, e.g. clicker, Mentimeter, Kahoot) to assess pre-knowledge, activate students, increase learning awareness, give student feedback, and gauge student performance during or after a lecture (Goldstein, 2007). With the development of the Internet and digital technology, education could step away from campus teaching by exploring novel virtual learning environments (e.g. Garreta-Domingo et al., 2018; Westera and Sloep, 2001). Examples of virtual learning environments are university degrees, e.g. the Open University (United Kingdom), or open online courses on learning platforms (e.g. edX, http://www.edx.org/, last access: 12 January 2022; for a course overview, use the search and keywords "hydrology" or "water"; Coursera, https://www.coursera.org/, last access: 12 January 2022; for a course overview, use the search and keywords "hydrology" or "water"; CUASHI, https://www.cuahsi.org/virtual-university, last access: 12 January 2022) and e-learning using e.g. virtual classrooms (Berry, 2019). While classroom lectures were optimized over the centuries, as Berry (2019) described, it is necessary to develop different strategies for e-learning that allow students to develop a structure, a sense of learning community, and social interactions in the virtual environment (Berry, 2019; Lehman, 2006).

In addition to "traditional" classroom or novel virtual learning environments, hydrology students need laboratory and field experiences to stimulate hypothesis testing and develop hydrological theories (Blume et al., 2017; Kleinhans et al., 2010) and prepare students to cope with all challenges in their professional life (John and Khan, 2018). In addition, the hydrology curriculum needs to also cover, next to wet hands-on experiences, programming skills (Kelleher et al., 2022; Merwade and Ruddell, 2012) and tinker with electronics to sense the environment (Hut et al., 2020; Kinar, 2021). Adding electronics to the curricula not only empowers, but also facilitates a student's hydrological learning and process understanding (Kinar, 2021) and can act as a stepping stone for collecting scientific spatiotemporal hydrometeorological data (Hut et al., 2010; Hund et al., 2016; Assendelft and van Meerveld, 2019; Wickert et al., 2019; Karachalios et al., 2021). Despite their importance, field activities are being increasingly reduced due to a generalized trend of decreasing funds allocated to water education and an increasing number of students. The cuts have "reached crisis proportions in many universities" (Eagleson, 1988; Nash et al., 1990; Wagener et al., 2012) and are a worrying development for hydrology education (Blume et al., 2017; Kleinhans et al., 2010; Vidon, 2015).

Since 2019, the COVID-19 pandemic has impacted the entire world. Different European countries followed different

Table 1. The different sections of the survey.

Information on respondent
Field of hydrology Role and courses taught Class size
Water education in pre-COVID-19 times
Teaching learning activities Classroom assessment techniques Type of examination
Water education during COVID-19
Which measures the university took to guarantee the educational continuity Was more time needed to prepare, hold, and wrap up lectures? Teaching aids to continue teaching Teaching learning activities Classroom assessment techniques Type of examination Was it necessary to adjust learning outcomes and student assessment? Perception of the situation by students and the teaching staff Did students reach the learning objectives? Was there a difference between spring and autumn? Which part in knowledge and skills in water education got lost due to COVID-19? Open feedback

strategies in an attempt to minimize or prevent the spread of the virus (Alemanno, 2020; ECDC, 2022). Common measures were social distancing and self-isolation, while schools (Raffetti and Di Baldassarre, 2022) and universities were closed (Schleicher, 2020). Suddenly universities were forced to move from class to distance teaching (Stracke et al., 2022). Schaefli (2021) summarizes nicely a hydrology teacher's perspective of all the challenges involved due to this sudden shift to distance teaching:

> "timing was perfect: start of the semester, start of online teaching, video conference infrastructure unavailable, three kids at home and me, a hydrology teacher who has never produced any kind of video exceeding a 20 s cell phone video".

Not only was little time available to prepare high-quality teaching material for distance teaching, but there was also a lack of experience in distance teaching. In addition, practical educational elements were canceled (e.g. field excursion, survey among Swedish universities; Fischer, 2020), and COVID-19-related illness and motivational and emotional distress were observed (Aristovnik et al., 2020; Bormann et al., 2021; Marzoli et al., 2021; Romeo et al., 2021), which might have affected knowledge transfer in hydrology education negatively.

Taking part in an academic teaching training course at Uppsala University during COVID-19, we got curious about how COVID-19 might impact European water education. We chose to investigate this in the mandatory project of the course. With the special issue "Hydrology education in a changing world" (Seibert et al., 2013) serving as a basis for this study, we conducted an online survey (November 2020 to March 2021) focusing on (1) common teaching methods and classroom assessment and examination techniques in pre-COVID-19 times and (2) how these education methods and techniques changed during COVID-19. In the spirit of "it takes a community to raise a hydrologist" (Wagener et al., 2012) during the pandemic and beyond, the aim of this paper is to communicate and potentially learn from the results of our survey.

2 Methods

We based our survey on a survey by Fischer (2020) and extended it to investigate how COVID-19 might impact European water education. The survey consisted of three sections: (1) information on the respondent, (2) water education pre-COVID-19, and (3) water education during COVID-19 (Table 1), which consisted of a total of 30 questions (Table A1) and should have taken approximately 10 min to answer. To reach as many people as possible and to obtain unbiased answers while respecting the privacy of the participants, the survey was set up as an anonymous web form using Google Forms (a web application to create and share online forms and surveys, Google LLC). To have an unbiased result, a random sampling method reaching a high number of participants from the total population of hydrology teachers would be preferable (Gideon, 2012). However, to reach a large target audience, consisting of many hydrologists involved in university education across Europe (including student assistants, PhD students, lecturers/teachers, (assistant) professors, course administrators, and researchers) within a certain time frame to represent the COVID-19 zeitgeist, we adopted an ad hoc snowball sampling approach. The link to the survey was sent by e-mail to more than 200 contacts of the wider network of the authors, all part of different universities in water education across Europe (Berlin, Göttingen, Stuttgart, Bucharest, Hamburg, University of Zürich and ETH Zürich, University of Freiburg im Breisgau, TU Delft, VU Amsterdam, Wageningen, Florence, and members of the EU Cost "WATer isotopeS in the critical zONe" consisting of more than 110 colleagues and further to five random hydrologists). In addition, in the e-mail there was a request to spread the survey within the respective departments. The e-mail with a link to the form was sent in November 2020, with a reminder in March 2021. In addition, a post with the link to the survey was posted to a hydrology group on the social network Facebook. The authors of this group did not participate in the survey.

The obtained answers were summarized and presented in different graphs using MATLAB R2021a (MathWorks). The number or percentage of respondents for a given question or answer was represented as a bar or pie chart. Respondents' answers to more qualitative open questions were discussed in the text (in the case of few answers) or were represented as word clouds (if more than ∼ 15 answers were available). In a word cloud, the respondents' answers were summarized as text and the most frequent answers highlighted (increasing font size and color changing from grey to orange as the words became more frequent).

3 Results and discussion

3.1 Snapshot overview of water education in Europe

Twenty-eight respondents working at universities across Europe (Fig. 1) in the fields of hydrology, geohydrology, chemistry, fluid dynamics, soil mechanics, and environmental and civil engineering (Fig. 2a) answered the survey on how COVID-19 might impact European water education. Because the survey was set up to be anonymous, only the university name and country (Fig. 1b) were known. The 28 respondents consisted of researchers, lecturers, and different levels from professors to course administrators (Fig. 2b) who taught a wide variety of hydrology and water-related courses from bachelor to PhD level (Fig. 3a, b). Unfortunately, only a few universities per country responded to the survey, and some European countries were missing. The low response rate to our survey may be because the population of hydrology teachers was too small or because our e-mail with the survey link was flagged as spam or not forwarded within the respective departments. COVID-19 aroused the curiosity of many scientists and educators (including the authors) in studying its effects on education in various scientific fields (Aristovnik et al., 2020; Eklund et al., 2022; Fischer, 2020; Bormann et al., 2021; Fox et al., 2021; Gonzalez et al., 2020; Haley et al., 2021; Keržič et al., 2021; Marzoli et al., 2021; Romeo et al., 2021; Salling Olesen et al., 2021; Wanigasooriya et al., 2021; Stracke et al., 2022). The many surveys conducted in relation to COVID-19 might have caused a certain survey fatigue, as de Koning et al. (2021) described, which may also have been the case with our study. Given the few respondents, a more detailed investigation should be carried out. However, the results are of interest as they provide a first impression, similar to a snapshot sample campaign (a common and useful method to infer the spatial process within a catchment, e.g. Likens and Buso, 2006; Temnerud et al., 2007; Fischer et al., 2015; Floriancic et al., 2019), of the state of hydrology and water education across Europe as a result of the COVID-19 pandemic.

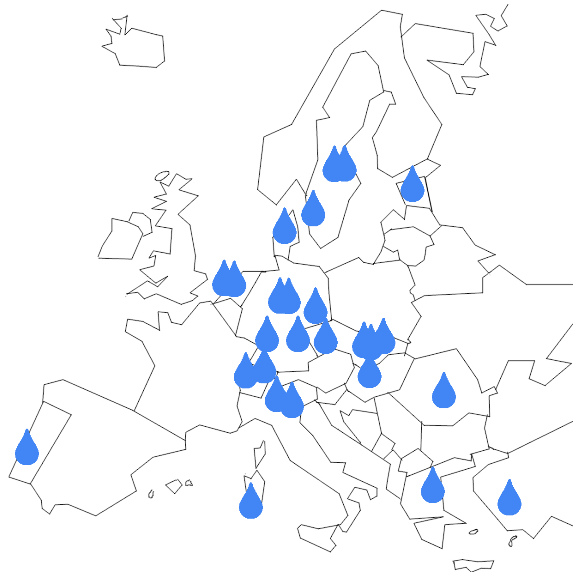

Figure 1. Schematized map of Europe where respondents to the survey are indicated as water droplets.

3.2 Water education in pre-COVID-19 times

Our survey builds on and aligns with Wagener et al. (2012) in terms of taught courses, course level, and the number of students per course (10 to more than 40 students, Fig. 3). Furthermore, our study provides a more detailed overview of the most common teaching format used by the respondents in pre-COVID-19 times, which were lectures (27 out of 28 respondents), followed by seminars (Fig. 4a). Laboratory work, experimental work, and fieldwork were used by less than 50 % of the participants as teaching formats. Peer teaching, roleplay, group discussion, and video recording seemed the less common practiced teaching formats in wa-

Figure 2. These respondents indicated in which part of water science they work in panel **(a)**, represented qualitatively as a word cloud. The larger the font, the more respondents indicated feeling connected to and working in it (multiple answers were possible). The different roles (levels) in water education indicated by the respondents given as a percentage **(b)**.

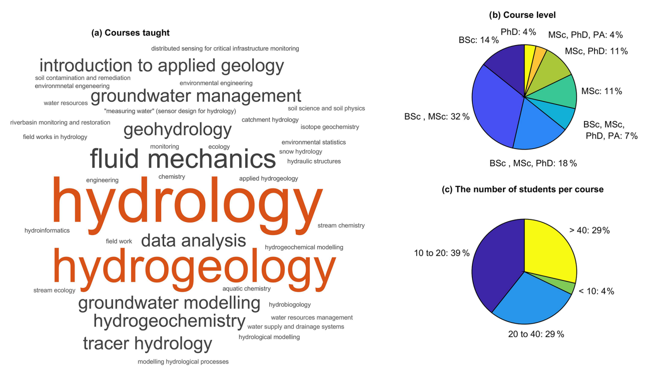

Figure 3. These respondents indicated which courses they taught, represented as a word cloud **(a)**. The larger the font, the more respondents indicated teaching the course (multiple answers were possible). The percentage of respondents teaching BSc- to PhD-level or post-academic (PA) courses **(b)**. The percentage of respondents indicated to have had < 10 up to > 40 students in their course **(c)**.

ter education and therefore can be considered more "exotic". Blume et al. (2017), Kleinhans et al. (2010), Vidon (2015), and Wagener et al. (2012) warned that more practical components are needed in the hydrological curriculum. Despite some novel teaching examples (AghaKouchak et al., 2013; Rodhe, 2012; Rusca et al., 2012; Seibert and Vis, 2012a, b; Lyon et al., 2013; Kinar, 2021) and despite exploring virtual learning environments (e.g. edX, Coursera, and CUASHI), a decade after these calls, it seems that traditional classroom lectures were the dominant formats of teaching. Only 42 % of the respondents indicated using CATS (specific software/-tools for questionnaires, survey-style quizzes, or peer review techniques) to improve and gauge the students' performance (Fig. 4b). Closed-book and oral exams or projects were commonly used examination formats (Fig. 4c). Hence, these results give the impression that hydrology and water education use rather traditional teaching methods and are far from the needed paradigm shift proposed by Seibert et al. (2013).

3.3 Water education during COVID-19

The beginning of 2020 came as a shock to research (CUAHSI Board of Directors & Officers, 2022), and especially for education when campus-based university education came to a halt. Hydrological education was forced to suddenly move from classroom to online teaching, which was only possible because of the available digital tools and technical infrastructure (Fig. 5). The practiced teaching format remained lectures (Fig. 4a). Instead, practical teaching methods, which are so important for hydrology, were terminated. To some extent, an increase in the use of "exotic" teaching formats such as pre-recorded videos and group discussions could be noticed (Fig. 4a).

Gonzalez et al. (2020) and Keržič et al. (2021) found that students were more focused during the pandemic, resulting in a positive study performance. By contrast, our hydrology respondents indicated that students were less focused during the lectures (Fig. 6d), student learning was impacted negatively (reported by 67 % of the respondents), and it was difficult to assess whether students reached their learning goals (Fig. 7e). These opposite observations could be explained by the use of CATs by Gonzalez et al. (2020) compared to the majority of the respondents of this study, who indicated not using or not being familiar with CATs during pre-COVID-19 teaching (Fig. 4b). Hence, it is likely that CATs were also not used during COVID-19, making it hard for teachers to give student feedback and gauge the student performance in the online environment (Fig. 6d–f). Examinations changed from project work and written exams (open- and closed-book) on campus (Fig. 4c) to open-book take-home exams (Figs. 4c and 6b). Respondents indicated an overall negative up to very negative teaching experience due to an extra effort to prepare for exams, trusting students not to cheat (which is hard to control), and lowering the level of the exams and the quality of the education, hence the overall negative teaching experiences (open feedback, Figs. 7c and g, 8). In addition, from open feedback we derived challenges concerning digital poverty, digital equality, and digital competency faced in hydrology education during COVID-19:

- Teachers needed additional training to get accustomed to new digital tools and the virtual learning environment, including acquiring computer literacy
- Required personal electronic devices, e.g. laptops, tablets with pens, video cameras, microphones and headsets, lights and stable Internet connections
- Solving various computer problems (e.g. installing software and driver conflicts when attaching new devices and connection issues)
- Rethinking the organization of the learning process and designing a new time plan when moving the classes online

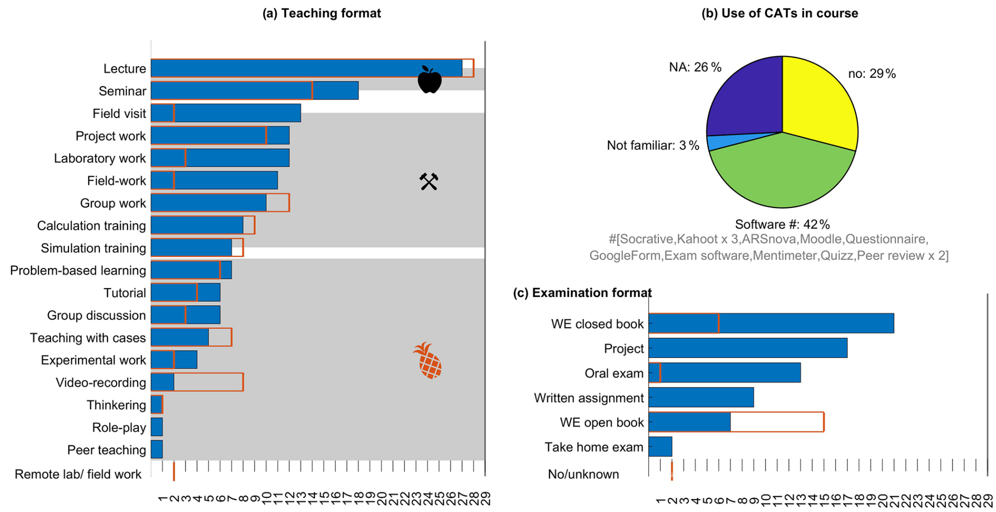

Figure 4. Traditional, practical, and exotic teaching formats indicated as 12, 1, or 12, respectively, used by the respondents before pre-COVID-19 measures (blue bars) and during COVID-19 measures (orange bar), where the x axis indicates the number of respondents **(a)**. Percentage of respondents who indicated using classroom assessment techniques (CATs), including a specific software application/tool, not answered (NA), not, or not familiar **(b)**. The respondents indicated using different examination formats before pre-COVID-19 measures (blue bars) and during COVID-19 measures (orange bar), where the x axis indicates the number of respondents **(c)**.

- Change from student-focused to teacher-focused surface learning
- Data privacy and cyber security for students and staff
- Adjusting the online courses to students with visual or hearing problems

The survey focused mainly on the year 2020, when some respondents indicated perceiving a difference between the spring and autumn semesters (Fig. 7h). The perceived differences are likely because different European countries imposed different infection control measures during the ongoing pandemic (ECDC, 2022; Alemanno, 2020), where instead of COVID-19 distance teaching, pre-COVID-19 teaching styles were again possible (campus teaching including laboratory work and fieldwork). After the finalization of the survey, additional hybrid formats appeared (e.g. students attending lectures in class and online). Such hybrid formats require other skills compared to on-campus or distance teaching only and require further research.

The challenges and negative hydrology teaching experience during 2020 could have been due to the sudden change from classroom to online teaching. Due to the lack of experience in online education, different teachers shared knowledge and resources on social media and websites (Table 2). Respondents indicated that universities provided technical support and training for distance teaching (Fig. 5a), which probably focused on technical rather than lesson design in an online environment. Generally, when teaching a course it is recommended to follow an integrated course design (Fink, 2013) which was described for hydrology classroom

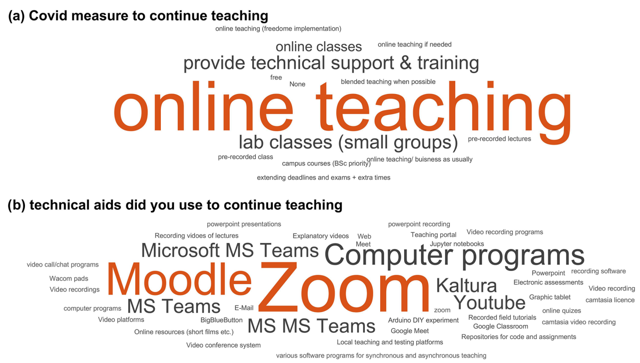

Figure 5. Measures **(a)** and technical aids **(b)** used by the respondents to continue teaching. The larger the font, the more respondents indicated using the measure or aid (multiple answers were possible).

teaching by Wagener et al. (2012) as the pre-COVID-19-developed Modular Curriculum for Hydrologic Advancement (MOCHA) ABCD lesson design concept consisting of planning, delivering, and evaluating to improve for next time. As described by Ellis et al. (2009) and Berry (2019), teaching in the online environment needs to consider the online digital context in the lecture design, workload, and interactivity and engage students through personal and professional interaction. Despite this framework, some exposure to virtual education, and how to optimize the student e-learning experience (Berry, 2019; Ellis et al., 2009; Lehman, 2006), the change to online teaching was somewhat improvised and a new experience for most of the teaching staff and students. In addition, the teaching material, tailored to classroom teach-

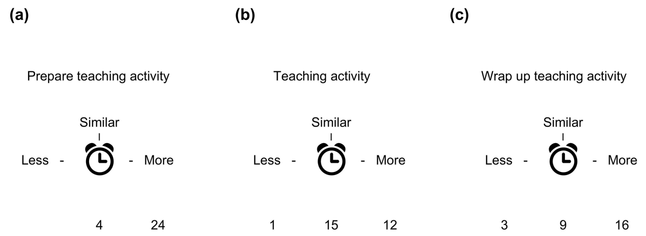

Figure 6. The amount of time (less, similar, or more) the respondents indicated having spent compared to pre-COVID-19 measures preparing the teaching activity **(a)**, during the teaching activity **(b)**, and wrapping up the teaching activity **(c)**. The numbers indicate the number of respondents.

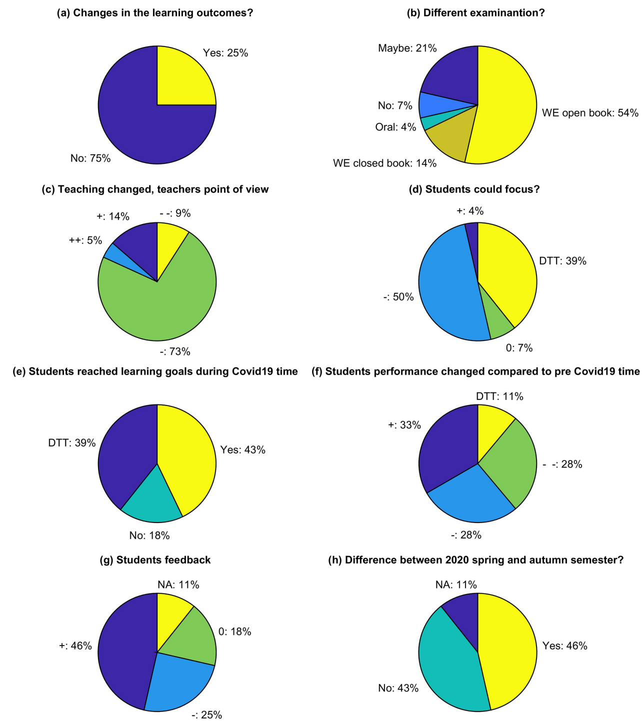

Figure 7. The percentage of respondents indicating that **(a)** the learning outcomes changed, **(b)** different examinations were used (written exam as WE), **(c)** teaching changed from a teacher's point **(d)**, students could focus, students could reach learning goals during COVID-19 measures **(e)**, students' performance changed compared to pre-COVID-19 measures **(f)**, the student feedback **(g)** and whether there was a difference in teaching between the 2020 spring and autumn semesters, with positive or more (+), neutral (0), negative (–), very negative (–), and difficult to tell (DTT).

ing, needed to be rapidly adjusted for online distance teaching. When teaching a class for the first time, the preparation can range between 3 and 5 h for a 1 h class, while subsequent years require only 1 to 2 h (Wagener et al., 2007). Similarly, teaching during COVID-19 required extra time for planning, delivering, and wrapping up teaching activities (Fig. 6). The extra time was comparable to the teaching load when preparing a new course, but it is expected to decrease the longer the COVID-19 situation lasts.

A time-independent factor contributing to the negative learning experience could be the loss of human interaction (Marzoli et al., 2021; Eklund et al., 2022; Ljunghammar and Waxell, 2020; Romeo et al., 2021). Traditional classroom teaching comprises student–teacher and student–student interaction (discussing e.g. lecture content and social and private life). Instead, in distance education such important physical, psychological, and social factors are missing or are limited (Berry, 2019; Lehman, 2006; Raffetti and Di Baldassarre, 2022), affecting the students' metacognition (Romeo et al., 2021; Eklund et al., 2022). A lack of social interaction can make students lose self-motivation or social skills or become unaware of limits and obligations, leading potentially to anxiety and depression (Marzoli et al., 2021; Eklund et al., 2022; Ljunghammar and Waxell, 2020; Romeo et al., 2021). This demonstrates that for students it is not sufficient to acquire only theoretical knowledge. However, it is necessary to grow as a person, apply the newly gained knowledge, and learn from mistakes in a stimulating and social environment (Ferretti et al., 2019; Glagovich and Swierczynski, 2004; Ryoo and Kekelis, 2018).

4 Concluding remarks and outlook

Twenty-eight respondents to our survey, working at universities across Europe in the field of hydrology, answered that, pre-COVID-19, conservative classroom lectures, laboratory work, and fieldwork were commonly used teaching formats in courses with 10 to more than 40 students. Similar results were found in the literature. Additionally, our survey indicated that less than half of the respondents indicated using classroom assessment techniques to improve and gauge the students' performance. Students were examined with closed-book or oral exams.

COVID-19 forced hydrological education to move suddenly from classroom to online teaching, which perhaps was only possible because of the available digital tools and technical infrastructure. The practiced teaching format remained lectures. Instead, practical teaching methods, which are so important for hydrology, were terminated.

Overall, the majority of the respondents reported that the COVID-19 crisis impacted student learning negatively up to very negatively. The online interaction was more difficult and cost extra time. Teachers lost student contact, and it was difficult to assess whether students achieved the learning outcomes. However, most of the respondents reported that they did not use classroom assessment techniques. The most affected learning activities were the ones that could not be moved to online teaching, such as laboratory work and fieldwork (Fig. 8). As discussed by Wagener et al. (2012), laboratory work and fieldwork were already strongly reduced from the teaching curricula in many universities in pre-COVID-19

Table 2. Overview of different positive novel teaching methods and resources (see the link in the bibliography for more content).

Activity	Category	Author	Potential and message
Distance fieldwork and/or lab work	Movie exercise	Stocker (2020)	Make fieldwork or excursions accessible to a wider educational public
Distance fieldwork and/or lab work	Course design	Mayer and Hug (2020)	Distance fieldwork could be offered as an add-on to traditional teaching
Distance fieldwork and/or lab work	Course design	Hut et al. (2020)	Make fieldwork or excursions accessible to a wider educational public
Teaching material	Collection of material	Sprenger (2020)	Community platform with different educational material
Teaching material	Sharing	Schaefli (2021)	Sharing most important, then quality
Classroom assessment technique	Circus/dance and movie	Brandimarte (2021)	Think out of the box and develop novel ways of learning useful for stimulating creativity, learning and outreach activities
Virtual meetings	Best practice	Gurung (2020)	Organize distance meetings
Blog	Blog post	Nassar (2021)	Share experience through social media

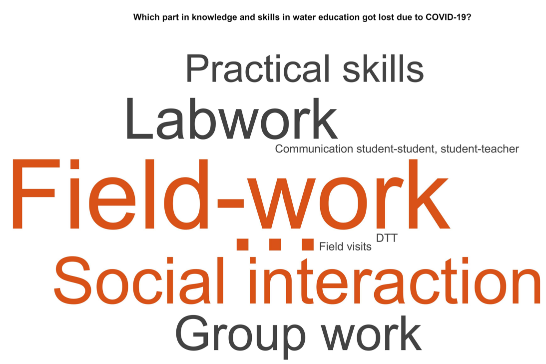

Figure 8. Which part in knowledge and skills in water education got lost due to COVID-19, indicated by the respondents. The larger the font, the more respondents indicated using the measure or aid (multiple answers were possible).

times, reaching a critical level. Hence, due to COVID-19 the important knowledge of process understanding in hydrology will be missing for at least several cohorts of hydrologists. Transferring passion for water-related topics and hydrological knowledge in a stimulating and social environment was disrupted, affecting several cohorts of students. In this way, COVID-19 caused a secondary effect on society and a loss of knowledge and skills, which are needed to tackle the existing and future local and global environmental challenges. This highlights that COVID-19 added a new layer of complexity on top of the already existing challenges in hydrological education pointed out by Wagener et al. (2012).

In the open feedback, respondents expressed the frustration that COVID-19 caused in teaching. However, next to all the COVID-19 misery, a spirit of optimism and a time of change could be noticed. COVID-19 made it possible to explore, improvise, and use novel teaching methods. Positive aspects were bottom-up initiatives sharing knowledge and resources on different social media and websites. Such efforts highlight that, even during extremes such as COVID-19, with creativity and improvising and sharing technical aspects and material as a community, e.g. in Sprenger (2020), it was possible to teach hydrology and overcome limitations during and beyond the pandemic. To learn from this COVID-19 experience and improve the online teaching and learning experience, the MOCHA ABCD lesson design, proposed by Wagener et al. (2012), should be adapted for the online environment. Such a to-be-developed "eMOCHA" lesson design for the online environment should include suggestions from e.g. Ellis et al. (2009) and Berry (2019b) considering the online digital context in the lecture design, workload, and interactivity and engage students through personal and professional interaction. Furthermore, one needs to evaluate and study which teaching formats worked, which elements are valuable to keep, and whether we, as a community, want to go back to the more traditional teaching styles in post-COVID-19 hydrology and water education or take the opportunity and finally take the next step in teaching hydrology and water education. Especially the range of practical and "exotic" teaching formats practiced during COVID-19 (Fig. 4a), home experiments using improvised low-budget or high-cost materials similar to e.g. Hut et al. (2020) and Kinar (2021), or learning how to program, e.g. Kelleher et al. (2022), taught at distance, could be an add-on to classical classroom teaching. Such activities promote learning by not only considering the lower cognitive domains of Bloom's taxonomy (a.k.a. Bloom's taxonomy of learning objectives, which identifies six cognitive levels from simple to more complex behavior, including knowledge, comprehension, application, analysis, synthesis, and evaluation/creation; Gogus, 2012), but also stimulating the higher cognitive levels by synthesizing, evaluating, and discussing water concepts in a safe social environment which facilitates the production of new original work. Even more, it could be a solution to repair the damage (reduced practical training) in hydrology and water education by making practical and "exotic" teaching formats accessible to all hydrology and water students. The aforementioned initiatives show that hydrology is not only a scientific community effort, but that above all it needs "a hydrological community to raise a hydrologist" (Wagener et al., 2012) who can solve old (Blöschl et al., 2019) and pose new hydrological questions.

The presented results are a first snapshot overview of how COVID-19 affected water education throughout Europe. The long-term effect on water education is uncertain and needs further analysis focusing not only on education, but also on social interactions, gender, and regional differences, to prepare hydrology education for future disruptive natural or other hazardous events.

Appendix A

Table A1. Questions from the survey "The effect of COVID-19 on water education".

No.	Question
1	At which University do you teach?
2	Please specify the country of your university where you are teaching at
3	What is the field are you are working in (e.g. hydrology, engineering, ecology, water manager, sociology ...)?
4	What is your role in teaching? (Multiple options possible)
5	Which level do you teach? (Multiple options possible)
6	Which courses do you teach (hydrology, ecology ...)?
7	How many students do you have on average in your courses? (One options possible)
8	Which format do you generally teach in your lectures (during non COVID-19 times)? (Multiple options possible)
9	Do you use classroom assessment techniques (kahoot, mentimeter, muddiest point, peer review ...) in your course(s)? If so, please specify below which (ones) are:
10	Which type of examination do you generally use to (test) assess the knowledge of students (more options possible)
11	Describe shortly which measures your university took during COVID-19 to guarantee the educational continuity.
12	How much time did you spend to PREPARE the teaching and learning activities compared to the pre-COVID-19 measures?
13	How much time did you spend DURING teaching and learning activities compared to the pre-COVID-19 measures? (e.g. extra time needed to explain concepts or give support to students)
14	How much time did you spend to AFTER the teaching and learning activities compared to the pre-COVID-19 measures? (Examination, wrap up of course, ...)
15	Which technical aids did you use to continue teaching (e.g. computer programs ...)?
16	Which teaching formats did you use to continue teaching? (Multiple options possible)
17	Did you need to make changes in the learning outcomes?
18	If you selected in question Qv17 yes, please specify how:
19	Did the assessment/examination of the course(s) change due to COVID-19?
20	If you selected in question Q19 yes, please specify how:
21	If the way of teaching changed, was this a positive or negative development from a teacher's point of view?
22	In case of negative development, what could be done to overcome these limitations?
23	Please fill in: Students were able to focus during the lectures:
24	Did you have the feeling that students could reach the learning objectives despite the COVID-19 measures?
25	If the way of teaching changed, how was the student feedback?
26	In case students had negative experiences, what could be done to overcome these limitations?
27	From your teaching experience, how good did students achieve their learning outcomes of the course(s) compared to pre-COVID-19 situation? The students performed
28	Was there a difference between the 2020 spring and autumn semester?
29	Which part in knowledge and skills in water education got lost due to COVID-19?
30	Open feedback (you can write here additional information you want to share concerning teaching during COVID-19)

Data availability. The anonymized response data are available as Supplement data, and the MATLAB script (to make Figs. 2–8) is available at https://github.com/hydrodroplets/COVID-19snapshotsample (last access: 5 August 2022; Fischer and Tatomir, 2022).

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Author contributions. BF and AT both designed, delivered and analyzed the survey. BF and AT co-wrote the paper.

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

Ethical statement. The work performed in this study is original, reflects the author's view and it does not engage in any form of malicious harm to other persons. The performed survey and literature study took place as part of a pedagogical training course at Uppsala University in 2020, the first year of the COVID-19 pandemic. This triggered the authors' curiosity about how COVID-19 might impact European water education. The survey took place in the wider research network of the authors involved in professionals in university education across Europe (including student assistants, PhD students, lecturers/teachers, (assistant) professors, course administrators, and researchers). The link to the online survey (Google Form) was sent by e-mail with a request to spread the survey within the respective departments. In addition, a post with the link to the survey was posted to a hydrology group on the social network Facebook. The authors of this group did not participate in the survey.

The survey was designed carefully to ensure that it did not cause any psychological or emotional distress. Participation was voluntary and anonymous, and participants were given the opportunity to consent or refuse participation. Participants could indicate voluntarily their e-mail address to receive the outcome of this study. The responses were kept confidential, no sensitive or identifying information was collected, and inappropriate wording in open-ended feedback, likely due to frustration, was represented in neutral wording covering the context. The anonymous data are provided as a supplement.

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