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

Benjamin M.C. Fischer [1] and Alex Tatomir [1&2]

[1] Department of Earth Sciences, Uppsala University, Uppsala, Sweden

[2] Department~~Dept.~~ of Applied Geology, University of Göttingen, Göttingen, Germany

Keywords: hydrology and water education, COVID-19, university education, Europe

Abstract

COVID-19 caused many disruptions, not only in society but also in university education~~ and teaching environments~~, including in~~for~~ 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 ~~impact~~ European water education. Consequently, we chose to investigate this aspect in the mandatory project~~The aim~~ of the course by conducting an online survey. In this paper, we ~~is to~~ 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~~We observed that overall water education changed throughout Europe due to COVID-19. A literature review of the common teaching techniques in the field and our survey indicates that hydrology educators use preponderantly conservative teaching styles, i.e., classical lectures, and therefore these were rather easily moved online during the pandemic. Overall, the COVID-19 crisis impacted student learning negatively (reported by 67%~~ of 28~~the~~ respondents, working in the field of hydrology at different Universities across Europe, showed that in the pre-COVID-19 classroom lectures, laboratory and fieldwork were commonly used teaching formats in courses with 10 to more than 40 students. These results agreed with those found literature.~~) while only 16.7% responded that the impact was positive.~~ 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. Mostinteraction made it more difficult for the teachers to assess the achievement of the learning outcomes. As most of the respondents (>(i.e., > 40%) reported that they do not usinge classroom assessment techniques to gauge, the students' performances. In addition, a loss of human interaction in the online environment was noticeable. Hence, and whether students reached their learning outcomes during distance teaching waswere largely unknown. Most affected learning activities were the ones that could not be moved to online teaching, such as laboratory and fieldwork. As a result, comprehensive hydrologicalfield work. Hence, the important knowledge mightof process understanding in hydrology will be missing for at least several cohortsgenerations of hydrologists. In this way, COVID-19 caused a secondary effect on society which needs skills to solve future challenges such ase.g., water management in a changing climate. Next to all of the negative, we observed positive COVID-19 -aspects, e.g., the hydrology a spirit of optimism, time of change, and community explored novel teaching formats, and shared teaching material and experiences online. COVID-19 forced hydrology teachersinitiatives could be noticed. COVID-19 made it necessary to explore, improvise and be creativedevelop novel teaching methods that could be used 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 makingand make practical and "exotic" nontraditional teaching formats accessible for all hydrology and water students.

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1. Introduction

Hydrology and water-related sciences cover among others: 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 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 et al., 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 modelling (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 high specific terminology and definitions (Venhuizen et al., 2019). Hence, it requires a broad academic education as well as continuous professional development of modern-day engineers and water professionals with uneven backgrounds (Popescu et al., 2012; Wagener et al., 2012). Students require strong skills in basic subjects like math, physics, soil, 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, 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, understand the spatiotemporal 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 novel teaching methods are explored. Classroom Assessment Techniques (CAT) are useful tools (e.g., exit ticket, polls, quizzes, muddiest point, peer review using analog (e.g., 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 steps 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 massive open online courses on learning platforms (e.g., edX, www.edx.org; for courses overview use search and keywords hydrology or water; Coursera, www.coursera.org, for courses overview use search and keywords hydrology or water; or CUASHI, www.cuahsi.org/education/cuahsi-virtual-university) 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 cover, next to wet hands-on experiences also programming skills (Kelleher et al., 2022; Merwade and Ruddell, 2012) and tinkering with electronics to sense the environment (Hut et al., 2020; Kinar, 2021). Adding electronics to the curricula, not only empowers but also facilitates 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 more and more reduced due to a generalized trend of decreasing funds allocated to water education and increasing the 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 impacted the entire world. Different European countries followed different 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 with all 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 20s cell phone video*". Not only that little time was available to prepare high-quality teaching material for distance teaching but 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, 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.

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The university education system we know today evolved over centuries and optimized its pedagogical approaches which initially focused on a few elite scholars to the current massive market-driven integrated learning with student mobility across Europe and the world (Forest et al., 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; Wagener et al., 2012; Seibert et al., 2013). The special issue "Hydrology education in a changing world" (Seibert et al., 2013) discusses in 28 papers the variety across hydrology education and different pedagogical approaches up to the year 2012. The pedagogical approaches ranged from teaching and learning activities using physical models in the classroom to explain the physical processes (Rodhe, 2012), teaching hydrological modelling (Seibert and Vis, 2012b), learning theoretical physical processes complemented with experimental work in the laboratory and field (Gleeson et al., 2012; Lyon et al., 2013). General aspects such as the implementation of integrative curricula (Blöschl et al., 2012), addressing 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).

Contemporary water education has a high complexity and involves multidisciplinary topics and is as Venhuizen et al. (2019) describe "flooded by jargon". Hence, it requires a broader academic education as well as continuous professional development of modern-day engineers and water professionals with uneven backgrounds (Popescu et al., 2012; Wagener et al., 2012). Students require strong skills in basic subjects like math, physics, soil, ecology, and social sciences which should be taught in well-structured courses which indicate 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 instance, the impact of 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 patterns in the landscape, conduct comparative studies to supplement learning through case studies, understand the time-varying characteristics of hydrological systems, use of space for time substitutions, and the modeling of interacting processes such as human-nature interactions and feedbacks.

Next to traditional methods in classroom environments, novel teaching methods are explored. With the development of the internet and digital technology, in recent years education can take a step away from campus teaching by exploring the novel virtual learning. Examples of virtual learning environments are massive open online courses on learning platforms (e.g., edX, www.edx.org; for courses overview use search and keywords hydrology or water; Coursera, www.coursera.org, for courses overview use search and keywords hydrology or water; or CUASHI, www.cuahsi.org/education/cuahsi-virtual-university) 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 structure, a sense of learning community and social interaction in the virtual environment (Lehman, 2006; Berry, 2019).

In addition to classroom lectures, it is necessary to teach field and laboratory experiences which stimulate hypothesis testing and develop hydrological theories (Kleinhans et al., 2010; Blume et al., 2017) and prepare students to cope with all challenges in their professional life (John and Khan, 2018). Students should not only get a wet hands-on experience but also practice tinkering with electronics to sense their environment (Hut et al., 2020; Kinar, 2021). Adding electronics to the curricula, not only empowers but also facilitates students hydrological learning and process understanding (Kinar, 2021) and can act as a stepping stone to collect 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). Unfortunately, due to a generalized trend of decreasing in funds allocated to water education and increasing the number of students, field activities are being more and more reduced. The cuts have "*reached crisis proportions in many universities*" (Nash et al., 1990; Eagleson, 1991; Wagener et al.,

~~2012) and should make the hydrology alarm bells ring (Kleinhans et al., 2010; Vidon, 2015; Blume et al., 2017).~~

~~Since 2019, the COVID-19 pandemic impacted the entire world and also the educational systems at all levels. In an attempt to stop the spread of the disease, many countries decided to close the schools and universities in a total lockdown (Schleicher, 2020). Typical measures included preventive measures such as social distancing and self-isolation. It might be due to the aforementioned technical developments and first steps in virtual education which saved and allowed Universities to continue teaching during the disruptive COVID-19 pandemic. Schaefli (2021) summarizes nicely a teacher's perspective with all challenges involved due to the 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 20s cell phone video*". Not only that little time was available to prepare high-quality teaching material for distance teaching but also the lack of experience in distance teaching. Despite the large effort and creativity to keep up the water education, a survey among Swedish Universities by Fischer (2020) revealed that important elements in water education such as field excursion were canceled and the contact between teachers and students got lost, affecting the knowledge transfer.~~

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 base for this study, we conducted an online survey (November 2020 to March 2021) focusing~~Consequently, we chose to investigate this in the mandatory project of the course by conducting an online survey (November 2020 to March 2021) which focused~~ on 1) common teaching methods and classroom assessment and examination techniques in pre-COVID-19 times and 2) how did these education methods and techniques change during COVID-19. In the spirit of "*it takes a community to raise a hydrologist*" (Wagener et al., 2012)~~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 in pre-COVID-19 and 3) Water education during COVID-19 (Table 1), which consisted of in total of 30 questions (Table A1) and should have taken approximately 10 minutes to answer. To reach as many people and 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 as many hydrologists involved in university education across Europe (To investigate the effect of COVID-19 on water education a survey was developed consisting of 30 questions (Table A1) which should take approximately 10 minutes to answer. The survey was aimed to source information from teaching and course administrative staff working in European universities including student assistants, Ph.D. 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.

The survey (see Appendix) was set up as different sections to get an overview of the respondents, pre-COVID-19 teaching activities, and during COVID-19 teaching and challenges and solutions enabling teaching during COVID-19 see Table 1.

The survey was set up as a web form using googleForm and it was sent by email 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 iBr., 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 5 random people). In addition, in the e-mail there was a request to spread the survey within the respective departments. The email 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 on the Facebook Hydrology group. The authors of this group did not participate in the survey.

The obtained answers were summarized and presented in different graphs using MATAB R2021a (MathWorks). The number or percentage of respondents for a given question or answer was represented as a bar or pie chart. More qualitative open questions with multiple responses were discussed in the text or represented as word clouds. In a word cloud, the respondents' answers are summarized or included as text, with the font size increasing and color-changing from grey to orange as the words become more frequent.

3. Results and discussion

3.1 Snapshot overview of water education in Europe

Twenty-eight respondents working at Universities across Europe (Figure 1) in the field of hydrology, geohydrology, chemistry, fluid dynamics, soil mechanics to environmental and civil engineering (Figure 2a) answered the survey how COVID-19 might impact European water education. Because the survey was set up to be as anonymous as possible with only the universities name and country (Figure 1b) being known. The 28 respondents consisted of researchers, lecturers, and different levels of professors to course administrators (Figure 2b) who taught a wide variety of hydrology and water-related courses from bachelor to Ph.D. graduate school level (Figure 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, our e-mail with the survey link was flagged as spam or not forwarded within the respective departments. COVID-19 arouse the curiosity of many scientists and educators (including the authors) to study 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 certain survey fatigue, as de Koning et al. (2021), which may also have been the case in our study. Given the few respondents a more detailed investigations should be carried. 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 spatial process within a catchment e.g., Likens and Buso (2006); Temnerud et al. (2007); Fischer et al. (2015); Floriancic et al., (2019)), on the state of hydrology and water education across Europe as a result of COVID-19 pandemic.

3. Results and discussion

3.1 Snapshot overview of water education in Europe

Twenty-eight respondents working at Universities across Europe (Figure 1) in the field of hydrology, geohydrology, chemistry, fluid dynamics, soil mechanics to environmental and civil engineering (Figure 2a) answered the survey "how the European water education got impacted due to COVID-19 measures". The respondents consisted of researchers, lecturers, different levels of professors to course administrators (Figure 2b) who teach a wide variety of hydrology and water-related courses from bachelor to Ph.D. graduate school level (Figure 3a & b). Similar to the observations made by Wagener et al. (2007) the number of students per course ranged between 10 to more than 40 students per course (Figure 3c).

The response rate to the survey was 14%, some European countries are missing and only a few universities per country responded to the survey. However, the results are of interest as they give a first impression, similar to a snapshot sample campaign, on the state of hydrology and water education across Europe as a result of COVID-19 pandemic (a snapshot sampling campaign is a common and useful method to infer spatial process within a catchment, e.g., Likens and Buso (2006); Temnerud et al. (2007); Fischer et al. (2015); Floriancic et al., (2019)).

3.2 Water education in pre-COVID-19 times

In pre-COVID-19 times lectures were the most common teaching format used by the respondents, (27 out of 28 respondents) followed by seminars (Figure 4a). Laboratory, experimental, and field work were used by less than 50% of the participants as teaching format. Peer teaching, role-play, group discussion, and video recording seem the more "exotic" and less practiced teaching formats in water education.

Classroom assessment techniques (CAT) are useful tools to give student feedback and gauge student performance during a lecture (Goldstein, 2007). The majority of the respondents did not use or answer that they are not familiar with CATs (Figure 4b). The respondents who indicated using CATS used specific software/tools ranging from questionnaire survey style to quizzes or peer review techniques (Figure 4b). To assess whether students achieved the learning goals of a course the written closed-book exams and project work were the most common formats while some participants used oral and take-home exams (Figure 4c).

Seibert et al. (2013) showcased the state of the art in water education and Kleinhans et al. (2010); Wagener et al. (2012); Vidon (2015) and Blume et al.(2017) warned that more practical components are needed in the hydrological curriculum. Despite some novel teaching examples (Rodhe, 2012; Rusca et al., 2012; Seibert and Vis, 2012a, b; AghaKouchak et al., 2013; Lyon et al., 2013; Kinar, 2021) and exploring virtual learning environments (e.g., edX, Coursera and CUASHI), a decade after these calls, it seems that traditional classroom lectures are still the dominant method of teaching. Methods to gauge students' performance are purely focused on the final exam while other methods seem to be less known to improve the students' performance. Hence, these results give the impression that hydrology and water education use rather conservative teaching methods and is 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 when campus-based university education came to a halt. COVID-19 acted as a catalyst that forced a move from classroom lectures to teaching lectures online at distance (Figure 4a). Although teaching online was a new experience for most of the teaching staff and students, the teaching format of lectures remained unchanged while practical teaching methods, so important for hydrology were terminated (Figure 4). Instead, an increase in the use of exotic teaching formats could be noticed such as prerecorded videos and group discussions.

The cancellation of the physical classes implied that online learning became the critical method of education which perhaps was only possible because of the digital tools and technical infrastructure available (Figure 5). Despite the available tools, the teaching material was tailored for classroom teaching and needed to be suddenly adjusted to online distance teaching. Generally, when teaching a course for the first time, the preparation ranges between 3 to 5 hours for a one hour course, while teaching the same course in subsequent years only requires 1 to 2 hours of preparation (Wagener et al., 2007). Similarly, teaching during COVID-19 required extra time was needed for teaching preparation, as well as, for holding and wrapping up teaching activities (Figure 6). The extra time is comparable with the teaching load when preparing a new course. The only notable difference is that when preparing a new course one can plan ahead, while during the COVID-19 pandemic, it became necessary to improvise and rapidly change from classroom to online teaching. The initial time investment for the preparation and development of the new distance teaching methods was high, but it is expected to decrease the longer the COVID-19 situation lasts. The survey focused mainly on the beginning of the pandemic period. Meanwhile, 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. Next to the time aspect, common challenges respondents faced/ noticed

- Rethinking the organization of the learning process and designing a new time plan – when moving the classes online, teachers need additional training, extra budget, new devices, stable internet connections, getting accustomed to new digital tools and the virtual learning environment. Some required personal gadgets, e.g., laptops, tablets with pens, video cameras, microphones and headsets, lights etc.
- Acquiring computer literacy – learning to deal with different platforms, and solving various computer problems with different degrees of difficulty with no support (e.g., installing software, driver conflicts when attaching new devices)
- Adjusting of the online courses to students with visual or hearing problems
- Change from student-focused to teacher-focused surface learning

Our survey builds on this foundation 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, Figure 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 (Figure 4a). Laboratory, experimental, and fieldwork were used by less than 50% of the participants as teaching formats. Peer teaching, role-play, group discussion, and video recording seemed the less common practiced teaching formats in water 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 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 (Figure 4b). Closed book and oral exams or projects were commonly used examination formats (Figure 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 hydrology research (CUAHSI Board of Directors &, 2022) but especially for hydrology 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 (Figure 5). The practiced teaching format remained lectures (Figure 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 prerecorded videos and group discussions could be noticed (Figure 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~~Data privacy and cyber security for students and staff~~ respondents indicated that students were less focused during the lecture (Figure 6d), student learning was impacted negatively (reported by 67% of the respondents) and it was difficult to assess whether students reached their learning goals (Figure 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 indicated to not use or were not familiar with CATs during pre-COVID-19 teaching (Figure 4b). Hence, it is likely CATs were also not used during COVID-19 made it hard for teachers to give student feedback and gauge the student performance in the online environment (Figure 6d-f). The examination changed from project work and written exams (open- and closed-book) on campus (Figure 4c) to open-book take-home exams (Figure 4c and 6b). Respondents indicated an overall negative up to very negatively teaching experience due to an extra effort to prepare for exams, trusting students to not cheat (which is hard to control) up to lowering the level of exams, quality of education, and thus to (open feedback, Figure 7c and g, Figure 8). In addition, from open feedback we derived different challenges to face in the hydrology education during COVID-19:

- Acquiring computer literacy – learning to deal with different platforms, solving various computer problems (e.g., installing software and driver conflicts when attaching new devices)
- Required personal gadgets, e.g., laptops, tablets with pens, video cameras, microphones and headsets, and lights Adjusting the online courses to students with visual or hearing problems
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Despite the effort and extra time, it might be that the overall quality of education might have decreased due to COVID-19. The respondents indicated that students were less focused during the lecture (Figure 6d) and it is difficult to tell whether students reached their learning goals (Figure 6e). However, since the majority of the respondents did not use CATs during pre-COVID-19 teaching and likely also not during COVID-19, in combination with the lost student-teacher interaction makes it is hard for teachers to give student feedback and gauge the student performance (Figure 6d-f). The examination changed from the written exam (open- and closed-book) on campus to open-book take-home exams(Figure 4c and 6b). Respondents indicated extra effort to prepare exams, trusting students to not cheat (which is hard to control) up to lowering the level of exams.

The loss in human interaction is a largely known secondary effect of the COVID-19 pandemic. Traditional classroom teaching involved student-teacher interaction and during breaks social student-

student interaction. The lack of interaction is an important psychological factor that is affecting students' metacognition, where students indicated a loss of self motivation (personal communication with students) showing that they were not fully aware of their limits, boundaries, and obligations making learning their own. At the base, it might be the loss of inter-human interaction between students and teachers and students and students in combination with the isolation, which is leading both teachers and students to have a negative experience (Figure 6c and g, Figure 8). Ultimately, such negative experience could lead to depression which was observed in a survey conducted by Uppsala University e.g. (Ljunghammar and Waxell, 2020).

- Half of the respondents perceived a difference in teaching between the 2020Data privacy and cyber security for students and staff
- Change from student-focused to teacher-focused surface learning
- Rethinking the organization of the learning process and designing a new time plan – when moving the classes online, teachers need additional training, extra budget, new devices, stable internet connections, and get accustomed to new digital tools and the virtual learning environment.

The survey focused mainly on the year 2020 where some respondents indicated to perceive a difference between the spring and autumn semester (Figure 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 again pre-COVID-19 teaching styles were possible (campus teaching including laboratory and fieldwork). After spring and autumn semester (Figure 7h) which is likely due to the different governmental imposed infection control measures by which pre-COVID-19 teaching styles were possible (campus teaching including field or laboratory work).

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 be due to the sudden change from classroom to online teaching. Respondents indicated universities provided technical support and training for distance teaching (Figure 5a). However, it is likely that due to the sudden change the support 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 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 improving 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, 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 somewhat improvised and a new experience for most of the teaching staff and students. In addition, the teaching material, tailored for classroom teaching, needed to be rapidly adjusted for online distance teaching. When teaching a class for the first time, the preparation can range between 3 to 5 hours for a one-hour class, while subsequent years require only 1 to 2 hours (Wagener et al., 2007). Similarly, teaching during COVID-19 required extra time for planning, delivering, and wrapping up teaching activities (Figure 6). The extra time was comparable with 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, 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 interactions can make students lose self-motivation, social skills, become unaware of limits and obligations leading ultimately 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. But 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).

Concluding remarks and outlook

Twenty-eight respondents to our survey, working at Universities across~~The presented results are only a first snapshot overview of how COVID-19 affected water education throughout~~ Europe in ~~. The presented results cover Europe and only a short period of time during~~ the field of hydrology, answered that ~~multi-peak pandemic. Therefore, the long-term effect on global water education needs to be seen. However, similar to a snapshot sampling campaign, these results can be extremely relevant to form an impression on how water education was impacted.~~

~~During~~ pre-COVID-19~~,~~ conservative classroom lectures, ~~and to a minor extent field- and~~ laboratory and fieldwork~~-work~~ were commonly used~~common~~ teaching formats in courses with 10 to more than 40 students. Similar results were found in 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 ~~that~~ were examined ~~mainly~~ in a 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~~ed~~ 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 do not use classroom assessment techniques. The most affected learning activities were the ones that could not be moved to online teaching, such as laboratory and fieldwork~~field work~~ (Figure 8). As discussed by Wagener et al. (2012),

~~(Wagener et al. 2012), field and~~ laboratory and fieldwork~~exercises~~ were already strongly reduced~~downscaled~~ from the teaching curricula in many universities in pre-COVID-19 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 and obtained in a stimulating and social environment ~~passion for water~~ got disrupted affecting generations of students. In this way, COVID-19 caused a secondary effect on society, 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 ~~challenges~~ already existing challenges in hydrological education pointed out by Wagener et al. (2012)~~(Wagener et al., 2012)~~.

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In the open feedback, respondents expressed their frustration of 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 (Table 2). Such efforts highlight that even during extremes such as COVID-19, with creativity, improvising, and sharing technical aspects and material as a community by e.g., 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, interactivity, engage students through personal and professional interaction. Furthermore, it needs to be evaluated and studied 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 make the next step in teaching hydrology and water education. Especially the range of practical and “exotic” teaching formats practiced during COVID-19 (Figure 4a), home experiments using improvised low-budget or high-cost materials similar to e.g., Hut et al. (2020) and Kinar (2021) or learn how to program e.g., Kelleher et al. (2022) taught at distance or 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 stimulate the higher cognitive levels by synthesizing, evaluating and discussing water concepts in a safe social environment which facilitate to produce 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 for all hydrology and water students. The aforementioned initiatives showcase that hydrology is not only a scientific community effort but 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 education, but also the social interactions, gender and regional differences to prepare hydrology education for future disruptive natural or other hazardous events.

Data availability

The anonymized response data is available as supplementary data and the MATLAB script (to make figure 2-8) is available on https://github.com/hydrodroplets/COVID-19

~~In the open feedback, respondents expressed their frustration. However, next to all the COVID-19 misery, a spirit of optimism and 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 (Table 2). Such efforts highlight that even during extremes such as COVID-19, with imagination, improvising, and by sharing as a community it is possible to teach hydrology and overcome limitations during a pandemic, and with potentials for beyond. It needs to be evaluated and studied what worked, which elements are valuable~~

~~to keep, and whether we as a community want to go back to the more conservative teaching styles in post-COVID-19 hydrology and water education. Or take the opportunity and finally make the next step in teaching hydrology and water education. Especially the range of practical and exotic teaching formats indicated in Figure 4a, using improvised low-budget or high-cost materials and thought at distance e.g. Hut et al. (2020), could be an add on to classical classroom teaching. Such activities promote learning, by not only stimulating the lower two-third of Bloom's taxonomy (remember, comprehend, apply and analyze water facts and concepts) but also to evaluating and discussing water concepts which facilitate to produce new original work. Even more, it could be a solution to repair the damage in hydrology and water education by making practical and exotic teaching formats accessible for all hydrology and water students. The aforementioned initiatives showcase that hydrology is not only a scientific community effort but 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 questions of hydrology.~~

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Tables

Table 1 The different sections of the survey.

Information on respondent	
	Field of hydrology
	Role and courses ta~~ho~~ught
	Class size
Water education in pre-COVID~~preCOVID~~-19 times	
	Teaching learning activities
	Classroom assessment techniques
	Type of examination
Water education during COVID-19	
	Which measures did the University take 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

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

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

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Figures

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

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

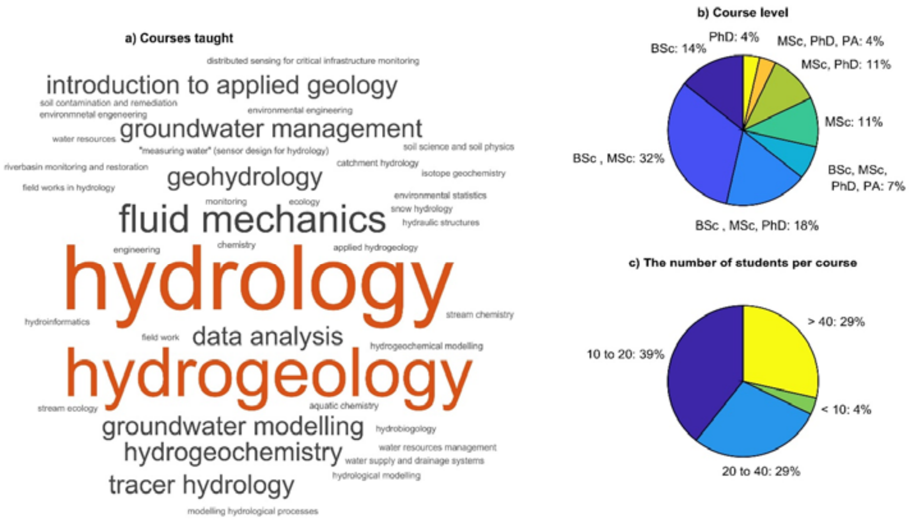

Figure 3 ***respondents indicated which courses they taught, represented as a word cloud (a). The larger the font, the more respondents indicated to teach the course (multiple answers were possible). The percentage of respondents teaching BSc to PhD level or post academic (PA) courses (b). The percentage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

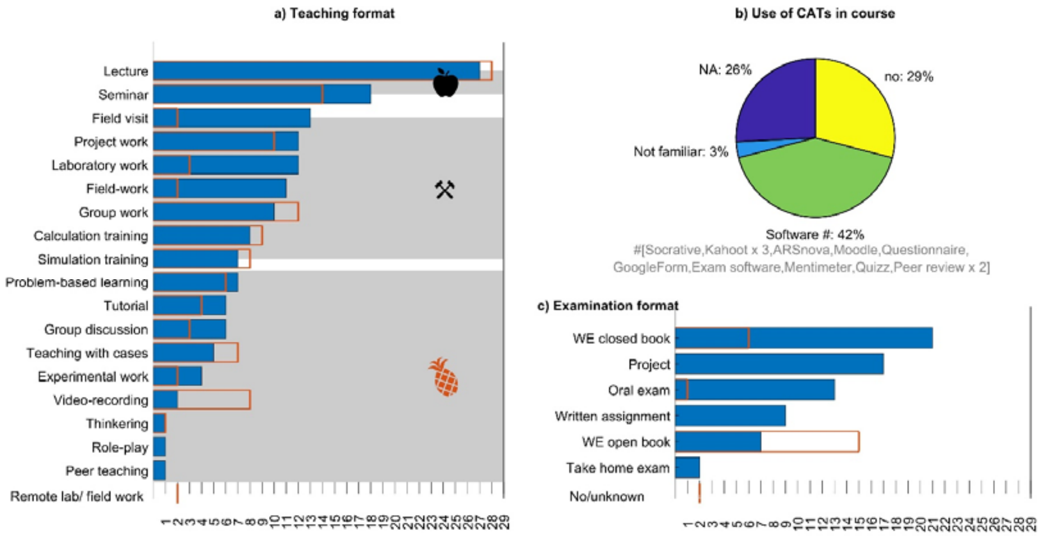

Figure 4 ***traditional, practical and exotic teaching formats indicated as , or respectively used by the respondents before pre-COVID~~preCOVID~~-19 measures (blue bars) and during COVID-19 measures (orange bar) where the x-axis indicates number of respondents (a). Percentage of respondents indicate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

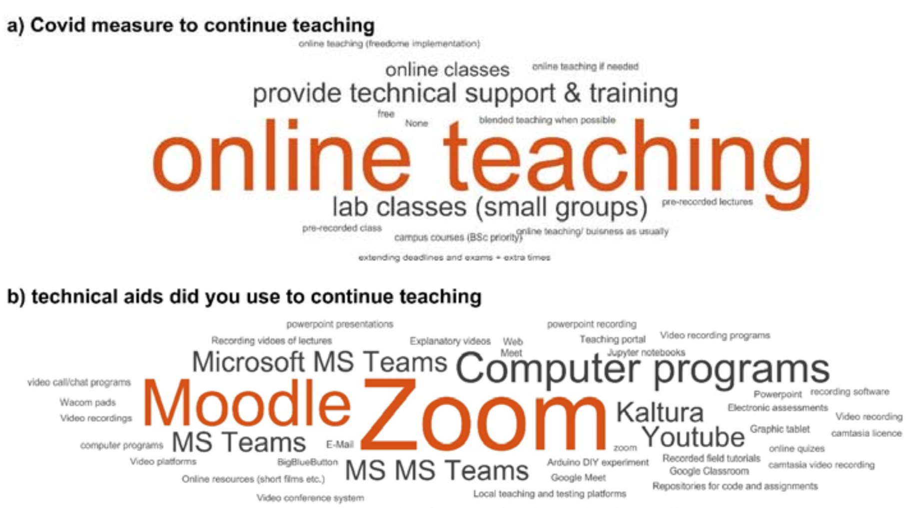

Figure 5 ***Measures (a) and technical aids (b) used by the respondents to continue teaching. The larger the font, the more respondents indicated to use the measure or aid (multiple answers were possible)***

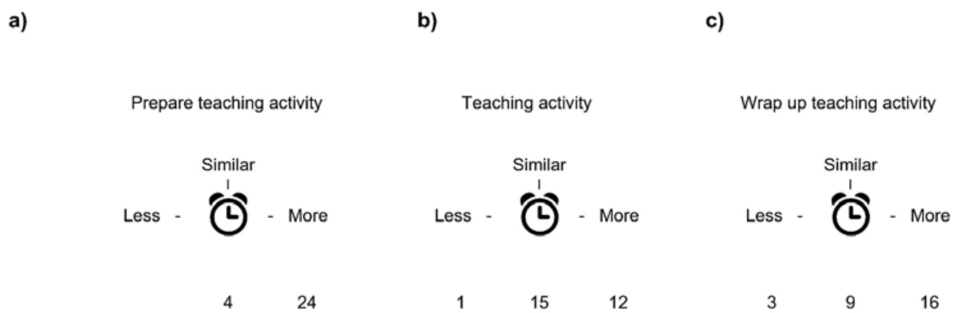

***Figure 6** The amount of time (less, similar or more) the respondents indicated to have spent compare to pre-COVID-19 measures preparing the teaching activity (a), during the teaching activity (b) and wrapping up the teaching activity (c). The numbers indicate the number of respondents.*

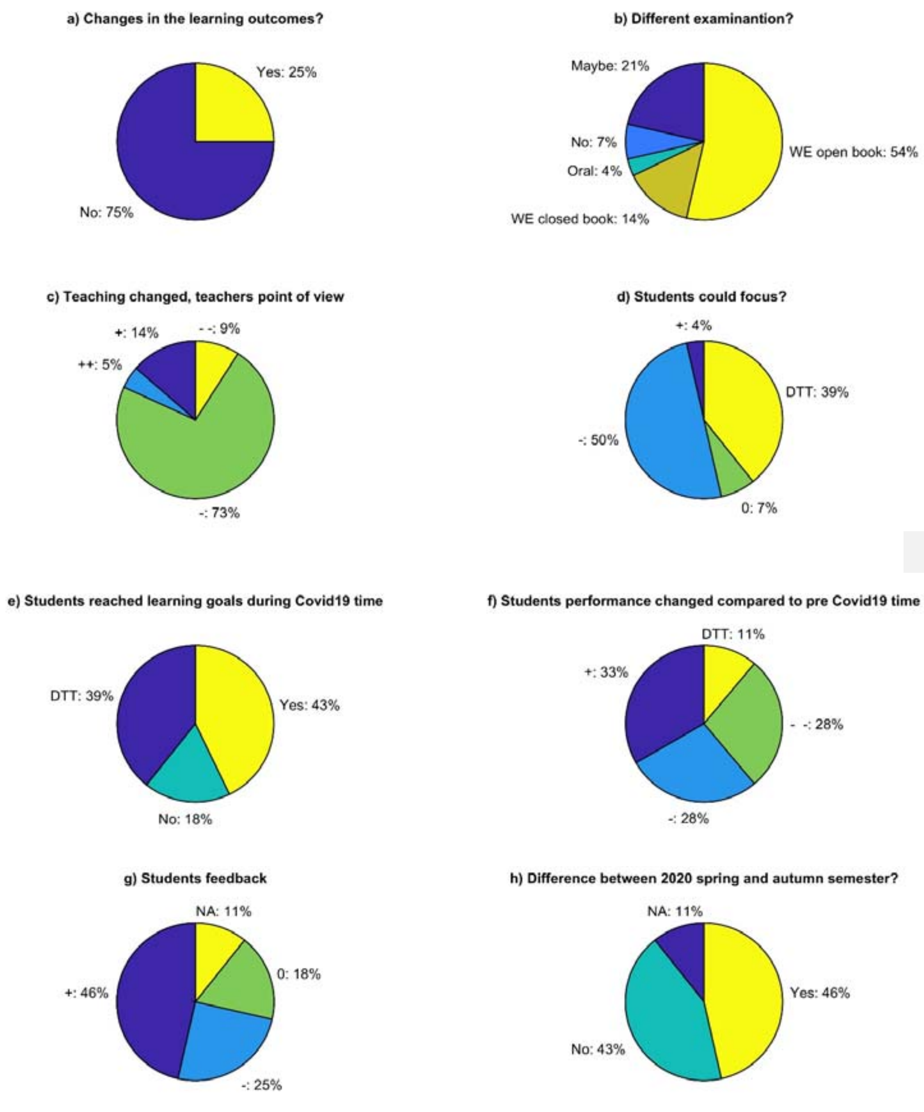

Figure 7 ***The percentage of respondents indicated that (a) the learning outcomes changed, (b) different examination were used (written exam as WE), (c) teaching changed from a teachers point (), students could focus (d), students could reach learning goals during COVID-19 measures (e), students' performance changed compare to COVID-19 measures (f), the student feedback (g) and if there was a difference in teaching between the 2020 spring and autumn semester? With positive or more (+), neutral (0), negative (-), very negative (--) and difficult to tell (DTT).***

***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 to use the measure or aid (multiple answers were possible).*

Appendix

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

#	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) asses 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 COVIDCovid-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 COVIDCovid-19?
30	Open feedback (you can write here additional information you want to share concerning teaching during COVID-19)