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Faculty perspectives on a collaborative, multi-institutional online hydrology graduate student training program

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The CUAHSI Virtual University is an interinstitutional graduate training framework that was developed to increase access to specialized hydrology courses for graduate students from participating US institutions. The program was designed to capitalize on the benefits of collaborative teaching, allowing students to differentiate their learning and access subject matter experts at multiple institutions, while enrolled in a single course at their home institution, through a framework of reciprocity. Although the CUAHSI Virtual University was developed prior to the COVID-19 pandemic, the resilience of its online education model to such disruptions to classroom teaching increases the urgency of understanding how effective such an approach is at achieving its goals and what challenges multi-institutional graduate training faces for sustainability and expansion within the water sciences or in other disciplines. To gain faculty perspectives on the program, we surveyed (1) water science graduate program faculty who had served as instructors in the program, (2) water science graduate program faculty who were aware of the program, but had not participated, and (3) departmental chairs of participating instructors. Our data show widespread agreement across respondent types that the program is positive for students, diversifying their educational opportunities and increasing access to subject matter experts. Concerns and factors limiting faculty involvement revolved around faculty workload and administrative barriers, including low enrollment at individual institutions. If these barriers can be surmounted, the CUAHSI Virtual University has the potential for wider participation within hydrology and adoption in other STEM disciplines.

KEYWORDS

graduate education, hydrologic sciences, collaborative teaching, online education, differentiated learning, STEM

Introduction

Graduate-level courses offer students the opportunity to gain breadth and depth within a focused discipline. The hydrologic sciences are a broad field with roots in the geosciences, civil engineering, agronomy, soil science, forestry, environmental science and other allied disciplines. Faculty within the hydrologic sciences tend to specialize in niche subdisciplines spanning surface and groundwaters, quantity and quality issues, and field, laboratory, and modeling methodologies. Individual institutions rarely have departments devoted to hydrology or enough faculty to cover all of the subdisciplines at the desired depth for graduate coursework. In hydrology education, the need for complementary breadth and depth has been conceptualized as creating T-shaped professionals, who have depth of training in a specific area (the vertical bar of the T) and competencies across specialties (the broad, horizontal bar) (Uhlenbrook and De Jong, 2012; McIntosh and Taylor, 2013). Interdisciplinary water science and engineering programs that have emerged at the graduate level tend to embrace the concept of T-shaped training, but disciplinary education is still the norm at the undergraduate level and in many graduate programs (Harshbarger and Evans, 1967; Ruddell and Wagener, 2015).

Graduate programs also offer students more latitude to follow their interests in choosing courses and research topics than they may have been able to do in their time as undergraduates. In this way, graduate education is a form of differentiated instruction,which is a pedagogical framework that provides students with a range of different opportunities for learning new material in response to students' diverse interests and abilities (Tomlinson, 1999, 2001). Differentiated instruction can take the form of differentiating content, process, or product (Boelens et al., 2018). Differentiated instruction, however, is generally conceived as existing within a classroom (e.g., Tomlinson et al., 2003), and evaluation of differentiated instruction approaches within individual graduate courses has been limited (Santangelo and Tomlinson, 2009). At a graduate curricular level, differentiated instruction, through providing choice of courses and ensuring sufficient depth of training, requires faculty who are subject matter experts (Hopkins and Unger, 2017), and it often results in small class sizes for specialized subjects (Nelson and Hevert, 1992). The prohibitive costs of faculty teaching low enrollment graduate classes is a challenge for which online education may represent one potential or partial solution, especially in a collaborative, multi-institutional context.

Online education has become more prevalent over the past decade, including at the graduate level in science and engineering disciplines (e.g., Martínez et al., 2019). In a 2005 article about online teaching in the engineering field, the authors predicted that specialization and leveraging expertise among institutions would occur as online education in engineering became more common and would be used to drive down replication costs at multiple institutions (Bourne et al., 2005). The authors also recommend that engineering colleges continue to explore blended learning and partnership activities to enhance online education, thereby improving reach and access for students and improving the breadth of coverage of engineering courses (Bourne et al., 2005). To date, there has been no comprehensive assessment of the practice, trends, and potential for online education in hydrology specifically.

One type of online or remote education is multi-institutional classes. Multi-institutional classes are not new in higher education, and long-standing successful examples include classes in the less commonly taught languages (e.g., GLCA https://www.glca.org/faculty/shared-languages-program/ and Big Ten Academic Alliance https://lctlpartnership.celta.msu.edu/). Despite examples of successful multi-institutional classes and programs (e.g., Wang et al., 2005; Perkins et al., 2012; de Róiste et al., 2015), such classes remain relatively uncommon. Multi-institutional classes generally rely on distance learning technologies, and advances in technology over the past two decades, including learning management systems and video conferencing technology, have expanded the potential for multi-institutional education. Another advantage of multi-institutional classes, like online classes more generally, is that students can attend from different locations simultaneously (e.g., de Róiste et al., 2015). To provide continuity of instruction during COVID-19 pandemic restrictions, Virginia Commonwealth University's Department of Surgery initiated a virtual, multi-institutional collaborative lecture series to provide surgical residents access to synchronous lectures from experts at over 50 participating surgery programs (Metchik et al., 2021). While the program was discontinued as restrictions were lifted, Metchik et al. (2021) suggest that programs like this would dismantle disparities in surgical programs by increasing access to experts from a wide range of institutions.

Collaboration across institutions can also take the form of faculty learning communities and community-produced curriculum. Faculty learning communities are groups of faculty who collaboratively engage to enhance teaching and learning, through discussion, seminars, scholarship, and community building (Cox, 2004; Daly, 2011). Developing a faculty learning community for hydrology education and producing community-published curriculum and materials are among the "grand challenges for hydrology education in the twenty-first century" articulated by Ruddell and Wagener (2015). Previous efforts toward creating and sustaining faculty learning communities and curriculum were expressed in the Modular Curriculum for Hydrologic Advancement (Wagener et al., 2012) and special issues of hydrology journals (Missingham and McIntosh, 2013; Seibert, 2013). Several data- and modeling-driven education efforts have also been undertaken (e.g., Sanchez et al., 2016; Maggioni et al., 2020). The rapid transition to online and remote education in response to the

COVID-19 pandemic has catalyzed another flurry of innovation in hydrology education and formalized sharing of existing online hydrology education resources and efforts (e.g., Gallagher et al., 2022; Gannon and McGuire, 2022; Kelleher et al., 2022; Schwarzenbach et al., 2022; Thompson et al., 2022; Weaver et al., 2022).

This research aims to understand the perceived benefits and limitations of multi-institutional online graduate student training in the hydrologic sciences by examining faculty perceptions of an existing model from the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI). The CUAHSI Virtual University (CVU) model is one in which graduate students choose among multiple monthlong modules taught by subject matter experts (Loheide, 2020), thus adopting the pedagogical framework of differentiated instruction. Further details of the program design, history, faculty, and envisioned benefits are in Section CUAHSI Virtual University. We seek to determine whether the benefits to the CVU model are perceived as high by water science faculty, and the barriers to participation are perceived as low. If this is the case, the CVU model may serve as a template for multi-institutional graduate student training in other disciplines.

We focus on faculty perceptions, rather than those of the students, because faculty have control over course offerings and curriculum choices. To test the idea that faculty perception of benefits vs. barriers influences participation in multi-institutional graduate training programs, and therefore the success and sustainability of the programs, we surveyed both water science faculty who have participated as CVU instructors and a comparable number of water science faculty who have not participated in the program, but who were keenly aware of it through service on CUAHSI Board of Directors. Specifically, we sought answers to the following questions:

1) What do faculty perceive as benefits of CVU to participating students, faculty, institutions, and the water science community?
2) What factors influence a faculty member's decision to participate in CVU? Specifically, do faculty who choose to participate in CVU have different perceptions of benefits and/or barriers than those who choose not to participate?
3) What are the prospects for sustainability of the CVU model within and beyond water science?

CUAHSI Virtual University

Program design

CVU is an inter-institutional graduate training framework that was developed by CUAHSI with the goals of (1) increasing access to specialized hydrology courses for graduate students from participating institutions and (2) capitalizing on the benefits of collaborative training (Loheide, 2020). To enable the education of T-shaped hydrology professionals (Uhlenbrook and De Jong, 2012; McIntosh and Taylor, 2013), while acknowledging faculty limitations at individual institutions, CVU is based on the concepts of collaboration and reciprocity, in which institutions broaden their course offerings by leveraging the strengths of other universities. Loheide (2020) describes the origins and inspiration for the program.

Participation in CVU requires that a faculty member of each university offers a synchronous, 4-week, online module that covers 1-credit of content to students from any participating university (Figure 1). The subject matter covered in the module is typically based on recent research advances in the faculty member's area of expertise and is intended to be sufficiently specialized that it would be unlikely to be offered on a regular basis on most campuses. Each year 6–12 modules are offered, depending on the number of participating instructors. Each student has the flexibility to select the three modules that are best aligned with their interests and background knowledge, allowing students to differentiate their instruction (Figure 1). Specialized modules allow students to gain depth of training in a particular specialty of interest to them (i.e., vertical bar of T-shaped training), but they can also allow students to gain exposure to topics and skills in other specialties (e.g., broad and horizontal training).

Modules are taught in two 90-min synchronous class sessions per week using video-conferencing software, and instructional content is delivered through a learning management system. The structure, activities, and summative assessments of each module are designed by the individual instructor, but student-student interactions, collaboration and networking across institutions are encouraged.

While no specific pedagogy is required, many instructors use active learning approaches and inclusive practices, like whole-class and small-group discussions of journal articles and in-class collaborative assignments (e.g., jointly creating a shared Jupyter notebook). Participating faculty meet several times prior to the semester to discuss what teaching strategies have been successful in previous years based on student feedback and their own perceptions. These discussions allow instructors to build relationships with other faculty and their competencies related to online teaching. Prior to the widespread adoption of online instruction during the COVID-19 pandemic, CVU was the first exposure to online teaching for the majority of participating faculty. Beyond CVU, approaches for active learning in online science and engineering courses have been increasingly promoted and disseminated over the course of the COVID-19 pandemic (e.g., Harris et al., 2020; Venton and Pompano, 2021).

Students are expected to take three modules (typically 1 per month during a semester), typically earning three graduate credits at their home institution. Usually, the course appears as a class with a title similar to "Special Topics in Hydrology"

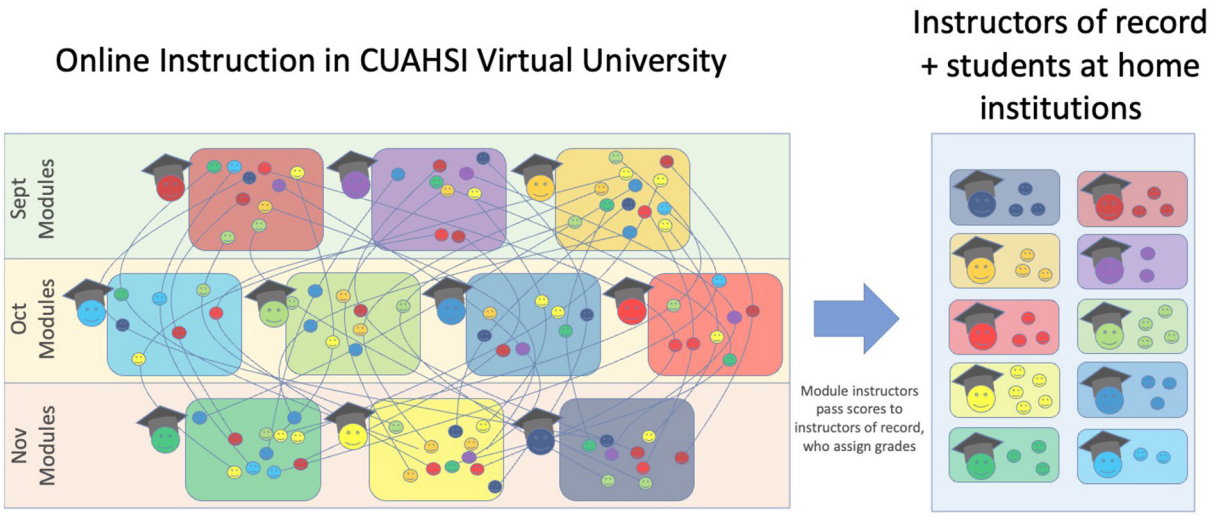

FIGURE 1
Instructors from participating universities teach month-long modules online to students (circles) from different institutions (represented by colors). Students choose the modules that interest them, resulting in differentiated instruction of content over the semester, as represented by the thin lines connecting the student icons. After the semester is over, module instructors pass scores to the instructors of record at each participating university, and these instructors assign grades to students from their home university.

in the course catalog at the home institution. The grade for the course is assigned by the instructor-of-record at the home institution based on the grading policies and culture at their university and the numerical scores that were assigned for all summative assessments (homework assignments, reading critiques, presentations, projects, quizzes, exams, etc.) for each of the modules taken by each student (Figure 1). In addition to the marks earned by students from each home institution and access to that students' work, each module instructor provides deidentified grade distributions to the instructor-of-record at the home institution.

While students take courses from instructors from across the country, it is important to note that no exchange of tuition dollars occurs, and students do not register at the other participating institutions. Rather, the students enroll at their home institutions and sign up for desired modules through CUAHSI. To maintain parity, institutional capacity is set to 15 students, and the module capacity is set to 45 students unless waived by the module instructor. To date, enrollments have never reached capacity.

CVU history and faculty

CVU started in 2017 with six modules offered to 44 students from six participating US universities. In 2021, 63 students, from 10 universities, enrolled in at least one of the 11 modules offered. Through 2021, a total of 286 graduate students have taken at least one CVU module and the average class size in a module is 15 students. Twenty-four unique modules have been offered through CVU, for a total of 43 modules taught between 2017 and 2021.

Through 2021, 23 faculty from 20 different universities have taught at least one CVU module. Of the participating universities, 19 have been located in the US and 1 in Europe. Twelve of the 23 CVU faculty have taught for 2 or more years. One faculty member has taught all 5 years. Eleven faculty have taught only one semester, with six of them being new participating instructors in 2021. Faculty departmental affiliations varied, with almost half (43%) coming from an earth sciences or geosciences-type program. Approximately 30% of faculty had an affiliation with an engineering department, while the remaining affiliations varied. Some faculty had multiple affiliations. Of the 19 US-based tenure-track faculty who have been instructors, four taught for CVU starting as assistant professors, six as associate professors, and nine as full professors.

Eligibility to teach a CVU module is limited to those who have standing as faculty members in graduate programs relevant to the hydrologic science. Participation in CVU is a bottom-up process initiated by interested prospective faculty, who then obtain permission from their institutions. CUAHSI solicits faculty participation starting about 1 year in advance, through its email list-serve and social media messages. Prospective faculty members submit a short application describing the proposed module and any prerequisite knowledge students would need, and each faculty member affirms that they have institutional permission to participate in the program. These applications are then reviewed and evaluated by CUAHSI staff and the CUAHSI

Education and Outreach Standing Committee. Evaluation is based on instructor eligibility, appropriateness of module scope for a 4-week session, and relevance of the module to water science. Feedback is provided to the potential instructor.

Envisioned benefits of CVU

Loheide (2020) enumerates the potential benefits of CVU participation for students, faculty, institutions, and the hydrologic science discipline. Potential benefits to students include (1) access to experts in specialized subdisciplines; (2) wider selection of course offerings; (3) networking and collaboration opportunities; and (4) development of new research skills. Potential benefits to participating faculty include (1) opportunities to teach in their research niche; (2) leveraging teaching effort; (3) ability to diversify educational opportunities for students; and (4) improved national visibility. Institutions potentially benefit from CVU through (1) increasing the depth and breadth of their courses, (2) improved national visibility; and (3) improved teaching efficiency. Finally, the discipline as a whole is envisioned to benefit *via* greater collaboration and faster dissemination of research innovations.

Methods

An internet-based survey was conducted using Qualtrics software in December 2021 and January 2022. Survey invitations were sent by email, with follow-up emails sent 2–3 weeks after the initial invitation. A survey was chosen as the appropriate method for this study to maximize the participation rate by minimizing expected time commitment for respondents.

Survey respondents were CVU instructors, their current department chairs, and 2017–2021 CUAHSI Board of Directors members. All members of the CUAHSI Board of Directors were faculty at institutions with graduate programs in water science, and therefore eligible to participate as instructors of CVU. Their inclusion in the survey is designed to represent faculty who were aware of CVU but had not participated in it as an instructor. Survey invitations were extended to 22 CVU faculty (participating instructors), 23 Board of Directors members who have not been CVU faculty (non-participating faculty), and 17 department chairs. The current chair of each instructor's department was contacted, regardless of who was chair at the time of CVU involvement. All survey responses were anonymous.

The survey covered faculty perceptions of CVU's benefits to participating students, faculty, and institutions, factors and concerns that influence the decision to teach for CVU, and potential benefits to the larger water community, aligning with the envisioned benefits enumerated in Loheide (2020) (Section Envisioned benefits of CVU). Survey questions were parallel where possible for participating instructors, non-participating faculty, and chairs. Our rationale for including non-participating faculty was to understand what factors influence faculty participation in multi-institutional graduate training programs and how perceptions of the benefits and barriers to participating in CVU might differ between water faculty who have and have not participated in the program.

Participating instructors were also asked the number of semesters for which they have taught in CVU, their plans for teaching in it again, and how their perceptions and concerns about teaching in CVU may have changed after they taught in it. Non-participating faculty and chairs were asked about their level of familiarity with CVU. Finally, all respondents were asked how CVU and the COVID-19 pandemic changed their perception of online classes. Survey questions are available at https://www.hydroshare.org/resource/2372f0c0a90d4061ae7f50a7f2a01cbd/.

Fisher's exact test, a non-parametric test similar to the Chi-square test useful for small datasets, was used to test differences in response among instructor and non-instructor respondents for Likert scale questions. All statistics were performed in R. Respondents were not required to answer every question, so the number of responses varies slightly across questions.

Results

Survey response rate and respondent demographics

The survey was administered to all past and current CVU faculty ("participating instructors"), CUAHSI Board of Directors members from 2017 to 2021 who had not taught for CVU ("non-participating faculty"), and department chairs of participating instructors. The survey was emailed to 63 individuals, including 22 participating instructors, 23 non-participating faculty, and 18 department chairs. A total of 37 responded to the survey, with an overall response rate of 58%. When disaggregated by experience with CVU, 18 of 22 participating instructors responded (82%) and 14 of 23 non-participating faculty responded (61%). Five of 18 (28%) department chairs completed the survey; two others replied to the email solicitation with some general thoughts about CVU but did not complete the survey.

Respondents who were non-participating faculty or department chairs were asked how familiar they were with CVU. Among non-participating faculty, 50% ($n = 7$) reported being moderately or extremely familiar with CVU, while 43% ($n = 6$) reported being somewhat familiar. One respondent (7%) reported being slightly familiar with the program. Among the five department chair respondents, three reported being somewhat familiar with CVU, one reported being moderately familiar, and one reported being extremely familiar with CVU. It is probable that department chairs who were more familiar with CVU were more likely to respond to the survey solicitation.

Participating instructors were not asked about their familiarity with the program and were assumed to be extremely familiar with it.

Among the survey respondents who have been participating instructors, 44% ($n = 8$) taught in CVU for 1 year, 44% ($n = 8$) taught for 2 or 3 years, and 11% ($n = 2$) taught in CVU for 4 years. Based on this, the survey respondents closely matched the overall instructor pool in terms of longevity of engagement with CVU, likely as a function of the high overall response rate for participating instructors (82%, $n = 18$).

Among participating instructors, 50% ($n = 9$) indicated that they planned to teach for CVU in 2022 or in future years, while 44% ($n = 8$) indicated that they were undecided. Only one respondent (5.5%) stated that they had no plans to teach for CVU in the future, commenting that a job change influenced their decision. In contrast, among non-instructor respondents, one respondent (7%) indicated that they planned to teach in CVU in the future, 50% ($n = 7$) indicated that they were undecided, and 43% ($n = 6$) indicated that they had no plans to teach for CVU in the future. At the time of survey administration, CVU applications for the 2022 semester had closed.

Benefits to participating students, faculty, and institutions

Almost all participating instructors and non-participating faculty somewhat or strongly agreed that CVU diversifies educational opportunities for students (89%, $n = 30$), increases the breadth (93%, $n = 30$), and depth (89%, $n = 30$) of opportunities for students, and increases student access to subject matter specialists (96%, $n = 30$) (Figure 2). There were no significant differences between participating instructors and non-participating faculty for these statements ($p > 0.05$). Among participating instructors, there was unanimous agreement ($n = 18$) that CVU increases breadth and access to specialists, while two instructors (of 18) somewhat disagreed that CVU increases depth of opportunity. One CVU instructor commented that CVU is "valuable for those of us in small graduate water programs" and another noted that the "students like the CVU offerings".

Student acquisition of skills was identified as an important benefit of CVU, by both participating instructors (recalling prior to their first participation) and non-participating faculty (Figure 3). Both groups largely agreed or strongly agreed that students could use skills developed in CVU for their research (thesis or manuscripts) and as part of their employment (during or following graduate school) and differences between groups were non-significant ($p = 0.73$ for research; $p = 0.12$ for employment). Participating instructors were also asked whether students had used skills developed in CVU for research or employment; 83% ($n = 15$) of participating instructors responded "yes" for research and 56% ($n = 10$) responded "yes" for employment. All the remaining responses were "unsure" for both questions. One instructor noted that "benefits to students depend on students' career trajectory".

Benefit to students was also the dominant theme of instructor answers in a free response about how teaching for CVU changed their perceptions of it. Six of 15 respondents noted the benefits to students. One instructor wrote, "I think CVU absolutely benefits the students in many ways. They have access to more experts, have the opportunity to learn different topics, and are able to network with a broader group of peers." Another instructor wrote, "I have been impressed how many thank you's I have gotten long after the class about how students have appreciated what they have learned and used it in their research. That means a lot to me."

CVU is a potential form of demonstrable broader impact associated with funded research. Recalling prior to their first involvement, 50% ($n = 9$) of participating instructors agreed or strongly agreed that CVU could fit within the broader impacts of a future proposal. In comparison, only 43% ($n = 6$) of non-participating faculty agreed or strongly agreed with that statement while considering CVU involvement (Figure 3). The difference was non-significant ($p = 0.21$). Among participating instructors considering the question retrospectively, 33% ($n = 6$) reported that CVU had been part of the broader impacts for a proposal, while 61% ($n = 11$) reported that it was likely to fit within the broader impacts of a future proposal. Three participating instructors (17%) reported it was unlikely to fit in a future proposal, while four participating instructors (22%) were unsure. All five department chair respondents indicated that teaching for CVU was likely to fit within the broader impacts of a future proposal.

Collaborations among faculty and students across institutions were envisaged as one advantage of CVU when it was launched, so we were interested in faculty perspectives on whether collaboration (projects, papers, and proposals) could be developed as a result of involvement in CVU (Figure 3). Recalling prior to involvement in CVU for the first time, a minority of participating instructors agreed or strongly agreed that a faculty collaboration (33%, $n = 6$) or student collaboration (39%, $n = 7$) could develop, and the level of agreement from non-participating faculty was similar ($p = 0.70$ for faculty collaboration; $p = 0.51$ for student collaboration). In reality, only two participating instructors (11%) reported that a faculty collaboration had developed as a result of CVU, while another two reported being unsure. Those two positive responses could represent only one collaborative pairing. The limited realization of student collaborations was similar, with three participating instructors (17%) reporting that they had occurred, and one instructor (6%) reported being unsure. However, collaborations are an outstanding feature of CVU for at least one instructor, who reported "CVU has led to deeper student-faculty and

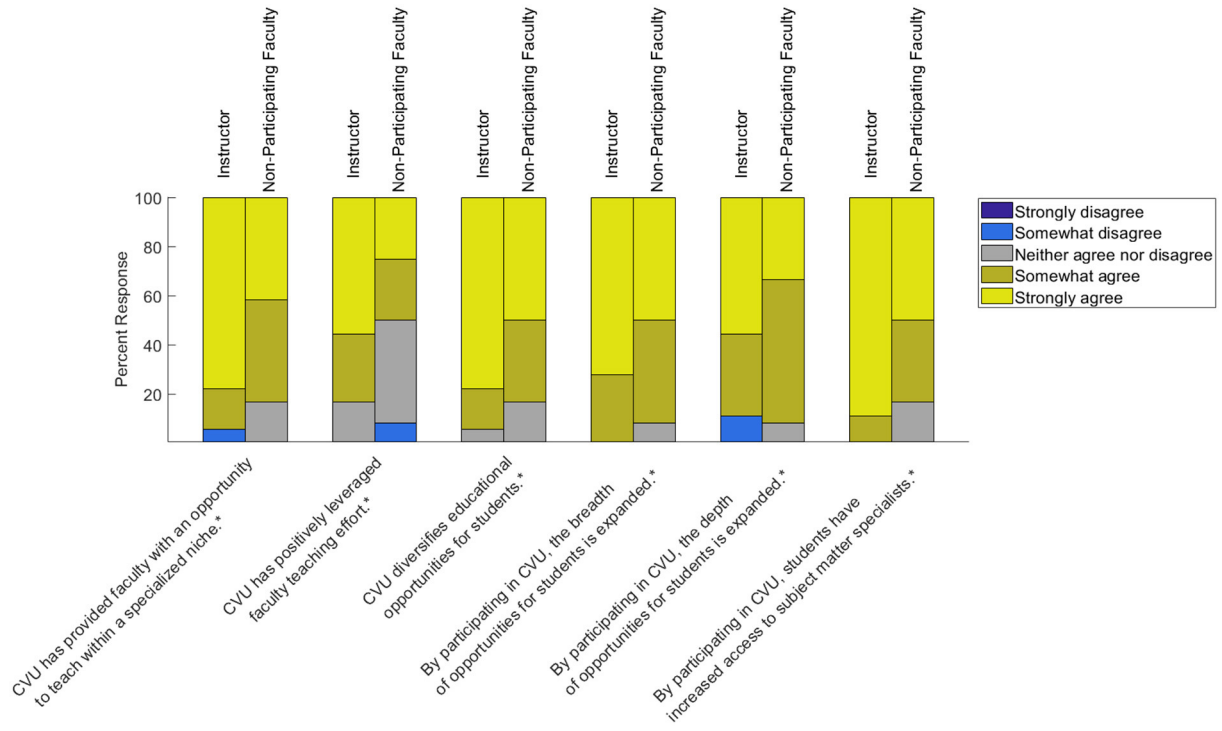

FIGURE 2
Levels of agreement to statements about benefits of CVU participation for students and faculty, as perceived by participating instructors and non-participating faculty. The asterisk symbol indicates that there were one or more non-responses to the statement.

faculty-faculty collaborations than I expected." While formal collaboration may be a rare outcome, informal connections may be more important. As one instructor noted, "the potential to connect with students in other universities was something that I didn't think about but was really what made the experience meaningful!"

Fourteen (of 18; 78%) CVU participating instructors strongly agreed that CVU offers the opportunity for faculty to teach within a specialized niche, while only 5 of 12 (42%) non-instructor respondents strongly agreed with that statement (Figure 2). The difference in the strength of agreement with this statement was statistically significant ($p = 0.049$). Despite the opportunity to teach a specialized topic, in a free response, two participating instructors described the challenges of fitting instruction into a 4-week module. One instructor wrote that they would have liked to develop a product with students from the CVU module, but that doing so "would be quite challenging as a month passes quickly". The other commented that if students didn't have the "proper background," "it was hard to bring them up to speed in such a short time".

While participating instructors overwhelmingly agreed (15 out of 18 somewhat or strongly agreed) that CVU positively leverages teaching efforts, non-participating faculty did not share that perception with six out of 12 respondents expressing either negative (somewhat disagree) or neutral responses to that statement (Figure 2). However, the difference was not statistically significant ($p = 0.17$). One instructor wrote, "My institution has embraced the CVU framework and it is now a regular part of my teaching load", while another noted "It's perhaps surprising/disappointing to hear that some of my co-teaching faculty have department chairs that resist (at least initially) their involvement. I am surprised that they don't see the potential value proposition."

Responses from the five department chairs showed similar sentiments. One commented "This is a fantastic program. Keep it up." Another indicated "There is a lot that I like about CVU, expanded access to courses for students, the high quality of the courses offered, the well-targeted and topical nature of offerings, and the short-course format makes it easy for students to fit into their programs of study."

Most participating instructors somewhat agreed that CVU has built a community of faculty (77%, $n = 14$) and community of students (50%, $n = 9$); a few (1 and 3, respectively) strongly agreed (Figure 4). Non-participating faculty responses were more neutral, with 7 (of 12) neither agreeing nor disagreeing with the statement "CVU has built a community of faculty" and 11 (of 12) neither agreeing nor disagreeing with the statement "CVU has built a community of students". The differences

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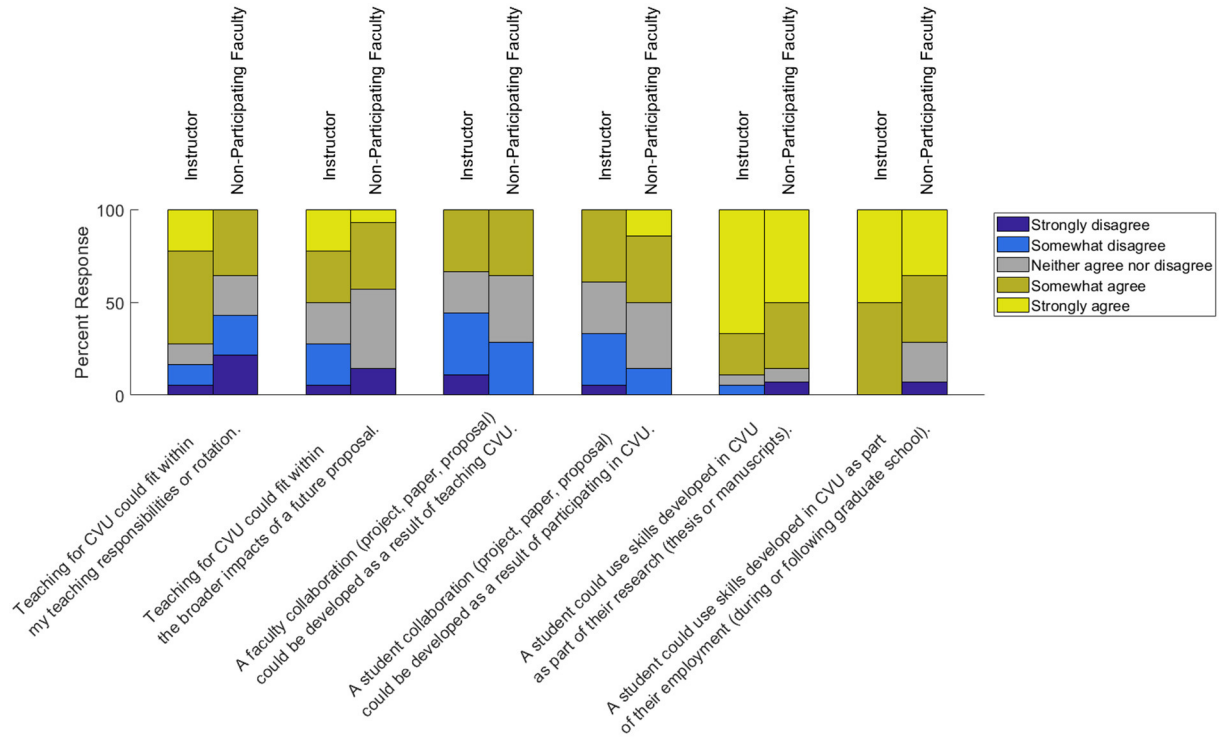

FIGURE 3
Levels of agreement to statements about outcomes from CVU participation for students and faculty. Instructors were asked to recall their perceptions prior to their first participation.

between participating instructor and non-participating faculty responses were statistically significant ($p = 0.014$ for faculty, $p = 0.0018$ for students).

When asked to consider the contributions CVU has made to the larger water science community, one CVU instructor stated "CVU is a wonderful contribution to the larger water community" while another noted "I'm not sure how widely CVU is known. But it would be great to expand it!" Most participating instructors became aware of other water graduate programs by participating in CVU (72%, $n = 13$) (Figure 4). However, CVU did not necessarily raise the national visibility of participating universities, with 67% ($n = 9$) of non-participating faculty and 50% ($n = 9$) of participating instructors neither agreeing nor disagreeing with the statement "CVU has improved the national visibility of participating universities' water programs". The difference between instructor and non-instructor responses was not significant ($p = 0.31$).

When asked to consider online instruction, participating instructors indicated that CVU changed the perception of online classes for water education, with over 55% ($n = 10$) agreeing with that statement (Figure 4). Only 42% ($n = 5$) of non-participating faculty agreed with that statement, but the difference with instructor responses was not significant ($p = 0.75$). A majority of both participating instructors and non-participating faculty agreed or strongly agreed that the COVID-19 pandemic changed their perceptions of online classes, with no significant differences between groups ($p = 0.40$). One CVU instructor wrote "Those of us who did CVU before the pandemic were way better prepared when the pandemic hit!"

Determinants of faculty participation in CVU

Perceived benefits to students were most frequently cited (40%, $n = 4$) as the biggest influence on the decision to teach for CVU in the future, by those who answered "yes" to whether they would teach for CVU in the future ($n = 10$). In contrast, benefits to students was listed as the biggest influence by only one of 22 respondents who said they were undecided or would not teach in CVU in the future. Beyond perceived benefits to students, other factors cited as the biggest influence on their positive decision to teach for CVU in the future were student participation at their university and teaching effort required vs. perceived benefit. One instructor who planned to teach for CVU in the future commented that "ability to share my specialty knowledge with students at universities who would not have access to it, and

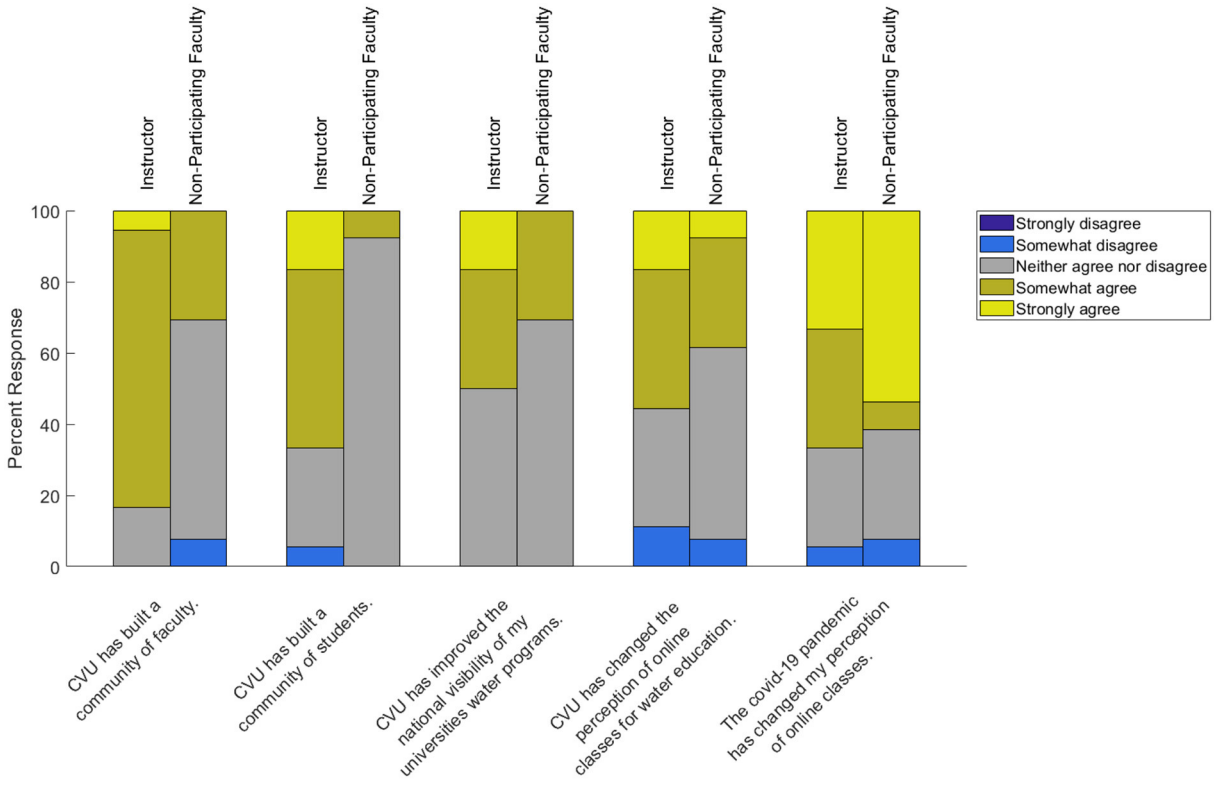

FIGURE 4
Levels of agreement with statements about CVU's role in community creation and online education.

the fact that they tell me thank you each term" was the biggest influence on their decision.

The home university plays a more important role in influencing the decision among those who have decided not to teach for CVU in the future. Of the seven respondents who said they would not teach for CVU in the future, the biggest influence for two respondents was the level of university support, for two respondents it was other classes that need to be offered at their university, and two respondents said the biggest influence was jobs that do not include regular teaching loads. Two non-participating faculty respondents cited teaching effort required vs. perceived benefits as the biggest influence on their decision.

Among those who were undecided about their future participation, the biggest influences were similar to those who have decided not to teach for CVU in the future. The level of support from their university was the most frequently cited influence. Five of seven (71%) undecided non-participating faculty respondents cited this as their biggest influence, as did two of eight (25%) undecided participating instructor respondents. Other classes that need to be offered and student participation at their university were also mentioned by more than one undecided respondent, while the remaining influences were only chosen by one undecided respondent. One undecided participating instructor noted that "teaching this enables students at my university to benefit from the offerings from other universities".

When contemplating CVU participation, the concerns held by those who went on to participate and those who did not differed somewhat (Figure 5). Institutional approval/support had the highest level of concern among non-participating faculty as they considered teaching in CVU, with 10 of 13 non-instructor respondents (77%) indicating moderate (3) or extreme (7) concern. Non-participating faculty were significantly more concerned about institutional approval/support than participating instructors ($p = 0.03$), among whom 7 out of 18 (39%) indicated moderate concern and only 1 (6%) indicated extreme concern. One non-participating faculty member noted that "I'd love to try teaching for it sometime, but right now, I don't have the time or political capital to deal with what the university would likely require for it." Over 70% of non-participating faculty respondents were moderately or extremely concerned about whether teaching in CVU would count toward workload, the time commitment, and the effort required to develop a new course. One non-participating faculty member volunteered: "My challenge is that I need more time in my day in order to be able to offer a course

via CVU." For participating instructors recalling their concerns prior to participating for the first time, the time commitment and the effort required to develop a new course were the most concerning, with 61% ($n = 11$) of participating instructor respondents indicating moderate or extreme concern prior to their initial involvement. Fit with other classes being offered was the least concerning item for participating instructors (11%, $n = 2$ moderately or extremely concerned) and online instruction was the least concerning for non-participating faculty (15%, $n = 2$ moderately or extremely concerned). No other single concern had a statistically significant difference between groups, but when all items asking about concerns prior to participation were summed, non-participating faculty expressed significantly more overall concern ($p = 0.008$).

The ability of teaching for CVU to fit within teaching responsibilities and rotations as a potentially important determinant of participation also emerged in other questions. A majority of participating instructors (72%, $n = 13$) agreed or strongly agreed that teaching for CVU could fit within their teaching responsibilities or rotations, while only a minority of non-participating faculty (36%, $n = 5$) agreed or strongly agreed with that statement (Figure 3). The difference was not statistically significant ($p = 0.24$), but non-participating faculty offered several related comments when asked what changes would make them more likely to participate in CVU. Non-participating faculty respondents volunteered that "nothing [needs to be changed] on CUAHSI's side. It would be more about how graduate teaching loads are assigned in my department"; that they would be more likely to participate "knowing I can replace a CVU course offering with one of my regularly offered courses at my own university and still get full credit for teaching," "teaching a module in CVU would be done as an 'overload' beyond normal teaching duties," and "It would have to be on top of my current teaching load, and I just cannot handle the extra work right now."

Two non-participating faculty respondents gave specific examples of institutional barriers to involvement in CVU. One respondent stated: "Getting credit hours from "other" places to count for our students can be very hard. Students have very strict lists of acceptable courses for their MS degree and getting "other" things to count is difficult." Another respondent volunteered: "Our campus is becoming more and more "business-like" in its financial affairs; the campus is now allocating funds to units based on undergrad and grad enrollment numbers. The CVU module would be offered as an "independent study" class, and the only official enrollees would be the students at the home institution. Administrators may not fully appreciate the benefits that the students on campus are getting from their enrollment in other models at different universities." Concerns about how enrollments count were echoed in the comments offered by department chairs.

University size and diversity of offerings may also influence whether faculty choose to participate in CVU. While we did not specifically ask about university size, research activity, or discipline in the survey, two non-participating faculty respondents discussed their university context when asked what changes would make it more likely for them to participate in CVU. One wrote "I teach at a school with a lot of hydrology offerings, which I know is rare. So I love the idea of CVU, but we have so much here that it's hard to take on another class given that my students already have really amazing options." The other respondent who brought up university context wrote that "CVU may be less attractive to students and instructors from large universities with large and comprehensive water and environmental science academic programs across many colleges and departments." Nevertheless, most of the universities who have participated in CVU have moderate to large water science and engineering foci across multiple departments.

Reflecting on the institutional barriers about which many non-participating faculty expressed concern, one noted "To be clear, I view this all as a major failing of the way universities are run. CVU is a wonderful and creative program that can really benefit hydrology education."

Sustainability of the CVU model

Despite the overwhelmingly positive perceptions of CVU benefits to participating students and faculty, survey respondents expressed concern about its ability to attract sufficient enrollment to maintain university support. When participating instructors were asked "What changes would make it more likely for you to continue participating in CVU?", five out of the 15 responses discussed student enrollment. As one instructor noted, "Increased student participation at my university would help lead to broader support. In general, it's an exceptionally hard time to get support for low-enrollment graduate level classes." One department chair wrote, "I'm willing to go a year or two with low enrollments, but the participating faculty members (at least at my institution) need to ensure they are offering courses that are valuable for students at our institution as well as the virtual audience. I suspect this is a common view among dep[artmen]t heads."

Participating instructors offered a number of ideas to make their continued involvement more likely, and such ideas might offset some enrollment concerns. Among the suggestions offered were extending student participation to senior year undergraduates, creating sequences of themed modules, making modules each worth a full course credit, and advertising modules to prospective faculty as they are accepted into CVU (i.e., having a rolling application window) so that potential instructors can see what other modules are being offered before committing to participation.

Department chairs were also asked whether the CVU framework would be useful for other disciplines within their department: one somewhat disagreed, two somewhat agreed,

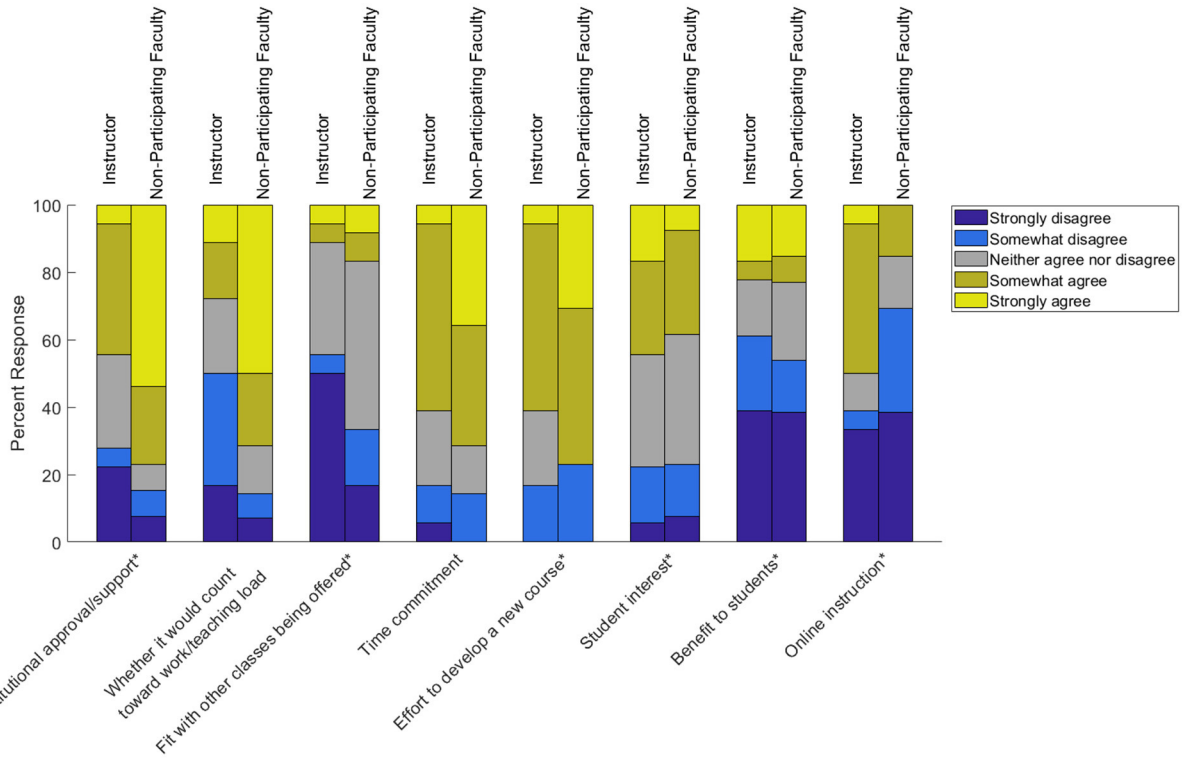

FIGURE 5
Levels of concern about various factors prior to first involvement (for instructors) and when contemplating involvement (for non-participating faculty). The asterisk symbol indicates that there were one or more non-responses to the statement.

and two provided a neutral response. We did not ask for an open-ended response to explain their reasoning.

Discussion

The benefits of CVU to participating students are at the center of the CVU design, and they emerge as the strongest and most consistent theme of survey responses. There was almost unanimous agreement that students were exposed to a greater breadth of content and had greater access to subject matter specialists because of their participation in CVU. Participating faculty also thought that CVU positively leveraged their teaching efforts, and the high degree of instructor retention suggests satisfaction with the program. Evidence for a wider appreciation of benefits to faculty and the water science community was less clear. Perceived administrative barriers around workload and enrollment are the largest challenges for sustainability and expansion of the CVU model. Despite a small sample size of survey respondents, which was influenced by the size of the CVU program, our findings suggest that the CVU model of short, specialized modules taught in a multi-institutional framework may be of interest to other science, technology, engineering, and mathematics (STEM) disciplines, particularly if ways to lower barriers to faculty participation can be identified.

CVU was envisioned to benefit students through access to experts in specialized subdisciplines of hydrology, by broadening the diversity of courses they could take, by helping them develop new research skills, and by providing an opportunity to network with students and faculty around the US (Loheide, 2020). From the perspective of participating instructors, all these objectives are being met. Among the non-participating faculty surveyed, there was also widespread agreement on the benefits to students, though the non-participant responses were somewhat less enthusiastic than among participating instructors. Lower agreement by non-participating faculty may reflect lower familiarity with the program and lack of contact with students enrolled in CVU. Multi-institutional graduate training programs may need to proactively create messages around positive student outcomes and faculty satisfaction to attract new participating faculty and institutions.

Participating instructors were unanimous that breadth of opportunity and access to experts were increased, while there was still strong, but slightly less agreement that the depth of opportunity had been increased. This suggests that participating faculty perceive that the short, specialized modules may enhance

broad training across specialties (horizontal bar of T-shaped hydrologic training, sensu Uhlenbrook and De Jong, 2012) more than increase deep training (the T's vertical bar). Perceptions of greater breadth than depth could be because students studied each module for 4 weeks, rather than a typical full semester course on a topic. If sequences of modules were developed around a theme (e.g., snow hydrology, food-energy-water nexus), it's possible that the increased depth of opportunity would be more fully realized. Sequenced modules could also mitigate students' perceptions that faculty covered too much material in 4 weeks (Loheide, 2020). However, it may be challenging to implement sequences while still allowing students free choice and a high degree of differentiation of instruction based on their interests and needs.

Participating instructors were confident that students had gained skills for research, which is consistent with student responses in 2017–2019, where 67–89% of students reported that they would or might use knowledge from CVU for their research (Loheide, 2020). A smaller majority of participating instructors reported that students could use skills gained in CVU for employment. No participating instructors were aware of students not using skills gained in CVU during future employment, but 44% were unsure they had done so. This higher unsure response rate for employment may be because faculty aren't as closely tracking what skills students use in their jobs post-graduation, and it represents an opportunity for future research.

While participating instructors agreed that CVU has built a community of students, the agreement was not as universal as it was for other measures of student benefits, and non-participating faculty were almost all neutral regarding student community. Faculty perceptions of student community may be limited, as they may not be aware of student networking and community building that occur outside of class sessions and the learning management system. Online multi-institutional programs like CVU might also consider developing an optional inter-university, in-person component (e.g., reception at a disciplinary conference) as a way of fostering student community that persists beyond the semester.

Benefits to faculty from participating in CVU informed the design of the program and were envisioned to include the opportunity to teach in a specialized niche and to leverage teaching effort in that instructors offer a 3-credit course in their university's course catalog but are only responsible for delivering one credit of content (Loheide, 2020). In questions directly asking about these benefits, participating instructors almost all agreed that they were being realized, and survey respondents who intended to teach for CVU in the future also described the effort required vs. perceived benefit as important to their decision. Conversely, institutional policies prevent faculty from leveraging teaching effort through CVU appear to be a principal barrier for non-participating faculty. These results suggest that teaching for CVU or similar programs cannot be treated as an uncompensated addition to faculty workload, and that the benefit to faculty is a principal contributor to the success of the model. It is not enough that there are almost universally recognized benefits for students; faculty should also get a direct benefit from participating as instructors.

An additional, unanticipated benefit recognized by participating instructors is the development of a community of faculty through their involvement in CVU. While not formally structured as a faculty learning community, CVU includes some elements of such learning communities, including opportunities to build areas of competence related to teaching and learning and venues for relationship-building across academic units (Daly, 2011; Ward and Selvester, 2012). CVU and other multi-institutional graduate teaching efforts could consciously build in aspects of faculty learning communities, as a way to strengthen community more broadly and improve the quality of instruction. Intentional creation of faculty learning communities associated with multi-institutional graduate training programs might also attract new faculty participants to them, especially if the extra time commitment of the learning community comes with clear benefits to the participating faculty.

At the institutional level, increased national recognition of water graduate programs and research strengths are an envisioned institutional benefit of CVU (Loheide, 2020). While many participating instructors thought that CVU had improved the visibility of participating water graduate programs, non-participating faculty and department chairs were more neutral, as any enhanced visibility may is likely limited to the network of participating institutions. However, our survey captures only faculty sentiments, and CVU students may be more aware of other schools as a result of their program participation. Broader impacts on grants are another potential institutional benefit of CVU, and notably, 100% of department chair respondents saw the potential for CVU to fit within the broader impacts on a future grant proposal. If multi-institutional graduate training programs that operate by recruiting interested faculty (as CVU does) identify ways to realize and enhance benefits at the institutional level, faculty interested in participating in such programs may be able to lower barriers to their participation.

The benefits of CVU to the larger water community and discipline are less clear in our survey results, although that could be because few questions were designed to directly measure these envisioned benefits. Loheide (2020) suggests that disciplinary benefits could include greater collaboration and community awareness of research activities and faster spread and acceptance of research innovations. Longer-term, the discipline is also likely to benefit as students who participated in CVU become faculty members and other water professionals, and they bring with them the research skills and professional networks they accrued through CVU.

CVU has high retention and satisfaction among participating instructors, and considerable interest in

involvement among non-participating faculty. Instructors are willing to commit to—or at least consider—teaching in the program in the future. Among those who have not previously taught in the program, most respondents are potentially open to doing so in the future, which suggests that there is potential for growth of the program. More broadly, high faculty interest and instructor satisfaction suggest that the CVU model might be attractive to other STEM disciplines.

Although non-participating faculty saw many potential benefits to students, themselves, and their institutions, they thought they could not participate in CVU, because of institutional barriers or lack of support. For example, non-participating faculty expressed higher concern overall, and about institutional approval specifically, compared to participating instructors recalling their thoughts prior to involvement in the program. While the pre-involvement concerns of CVU participating instructors may not be recalled as clearly after they successfully taught in CVU, the consistent themes expressed in non-instructor answers to both Likert-scale and open-ended questions require careful attention.

Why do non-participating faculty describe roadblocks to involvement that aren't perceived by participating instructors? We speculate that there are two possible explanations, and both may be at work across institutions. First, non-participating faculty may work at institutions where there are higher administrative or cultural barriers to participation in innovative, multi-institutional programs. Second, CVU participants may be more successful in overcoming perceived roadblocks, because of greater seniority or better informal networks and support within their university. Because we did not ask whether non-participating faculty had directly asked whether they would be allowed to participate in CVU, we cannot determine whether institutional barriers are codified or only perceived. In a few cases, non-instructor comments indicated that they had not approached their university about teaching for CVU or that they felt they lacked the capital to do so.

Whether institutional barriers to CVU participation are codified or only perceived, they may represent a significant challenge to the sustainability and expansion of the CVU model. If CVU has penetrated the universities where faculty and administration are willing to adopt an innovative, multi-institutional teaching framework, there may be little scope to expand or rotate participation. Conversely, if CVU participation is limited by current faculty awareness and interest, the potential to expand may be large, either within hydrologic science or with a CVU-like model in other disciplines. Future work should explicitly examine university policies and culture around multi-institutional teaching collaborations, perhaps in a hypothetical rather than a CVU-specific context.

Concerns about low enrollment in CVU were found across department chairs, non-participating faculty, and even some participating instructors. CVU may be seen as serving a relatively small student population per university, and with universities requiring minimum enrollments or rewarding higher enrollments, some academic units may not be easily able to justify using faculty workload to teach in the program. This tension between enrollment and workload may contribute to the institutional barriers perceived by non-participating faculty, and it may influence the type of institution that participates in CVU or similar programs. Two respondents described being at universities with large water science programs and feeling like their graduate students could take an adequate amount of hydrology from existing in-house courses. Institutions like this might have the least concerns about sufficient enrollment, but the least incentive to contribute to multi-institutional teaching efforts. Conversely, institutions with small graduate programs might gain the most from the advanced, modular CVU-like curriculum, but face the greatest challenge in achieving any required minimum enrollment.

To counter limitations to participation in multi-institutional graduate teaching that center on enrollment pressures, convincing administrators of benefits beyond enrollment (e.g., reputation) might be important. However, this was an area where the current survey did not clearly show strong results for CVU. Multi-institutional collaborative teaching efforts, like CVU could also actively recruit and promote modules that serve a broader, interdisciplinary student population, while still also fulfilling their role in providing niche disciplinary topics. For instance, CVU modules on "Geographical Information Systems for Terrain and Watershed Analysis," "Open and Reproducible Computing," and "Advances in Drone-Based Hydrology" have a technological focus with appeal beyond hydrology, while still focusing on applications to hydrologic science. However, simply offering some broadly appealing modules will not be sufficient if those modules aren't advertised at the appropriate stages to recruit new instructors and gain student registrations.

The COVID-19 pandemic was a profound test of the utility and limits of online education (e.g., Lowry et al., 2022; Thompson et al., 2022). Experience with teaching online through CVU may have helped some participating instructors be more prepared for the rapid shift to online instruction during the pandemic. While the difference was not statistically significant, participating instructors expressed more concern about online teaching prior to their first involvement than non-participating faculty, but this may reflect the fact that some participating instructors first taught in CVU before the COVID-19 pandemic, while non-participating faculty are answering with the experience of the pandemic online transition in mind. Both groups indicated that the pandemic has changed their perception of online classes, but it is unclear whether that will translate into increased faculty participation in CVU. Recruitment of participating instructors for 2022 has now occurred, and the number of participating faculty is flat or slightly below previous years, with 8 modules anticipated. This anecdotally suggests that even though faculty have gained familiarity with online instruction, institutional barriers remain

and faculty may also be burned out or discouraged from teaching online as universities emphasize a return to in-person instruction in 2022.

In the long term, online education, especially with shared instructional models as found in CVU, is more resilient to disruptions than in-person instruction. While COVID-19 emphasized this resilience to university faculty around the world, online education and shared instruction also impart resilience to other health emergencies, natural disasters, and severe weather events (de Róiste et al., 2015). Proactively developing online frameworks like CVU in other disciplines and at the undergraduate level may provide a useful safety net for faculty in the event of future disruptions. The faculty and department chair perspectives in this study serve as lessons learned that could inform the development of these frameworks.

Conclusion

Multi-institutional online graduate training programs, like CVU, offer a way to provide depth and breadth of student training in disciplines, like hydrologic science, where the size of the faculty may be limited at individual institutions. CVU uses 4-week, specialized modules delivered synchronously online to allow graduate students to differentiate their learning and access specialist faculty and knowledge unavailable at their home institution. In this research, we examined CVU as a case study of multi-institutional online graduate training programs and specifically investigated how faculty who had participated in CVU, along with similar non-participating faculty, viewed the benefits of CVU and the barriers to participation.

Overall, there was a strong faculty consensus that CVU enhances the breadth of training for participating graduate students and gives them access to subject matter specialists. Participating faculty also felt they benefited through positively leveraging their teaching load and becoming part of a community of faculty. These faculty-perceived benefits to students and themselves, along with high instructor retention and interest among non-participating faculty, suggests that the CVU model has the potential for sustainability and expansion within and beyond hydrologic science.

However, non-participating faculty responses were very revealing about the limitations of the CVU model, with perceived administrative barriers around workload and enrollment emerging as the largest challenges. Finding ways to mitigate these barriers may be necessary for sustaining and growing multi-institutional graduate training programs like CVU that depend on interested prospective faculty gaining institutional approval. Emphasizing the resilience of online, multi-institutional programs to disruptions, like the COVID-19 pandemic, might be one approach to do so.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: on Hydroshare at http://www.hydroshare.org/resource/2372f0c0a90d4061ae7f50a7f2a01cbd.

Ethics statement

The studies involving human participants were reviewed and approved by Kent State University Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AJ obtained IRB approval, administered the survey, and performed the statistical analysis of the results. SL created the figures. All authors contributed to the conceptualized and designed the survey and manuscript, analyzed the data, wrote sections of the manuscript, contributed to manuscript revision, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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