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Integrating a Real-Time Environmental Monitoring Lab into University and Community College Courses*

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The Learning Enhanced Watershed Assessment System (LEWAS) is a high-frequency, real-time environmental monitoring lab on the Virginia Tech campus that supports watershed research and education. Student-centered modules that incorporate hands-on activities and LEWAS data have been implemented into a senior level hydrology course at VT (30 students) and several freshman level introductory engineering courses at Virginia Western Community College (73 students). A multi-loop assessment plan demonstrates how researchers at a large public university can collaborate with community college faculty to improve assessment methods and classroom module development. Assessment results show student learning gains through active and collaborative LEWAS-based learning modules. A pilot test of a LEWAS-based interactive online educational tool called the Online Watershed Learning System (OWLS), which allows students to access real-time data, virtually explore the LEWAS watershed, and examine case studies, has also produced results that indicate that student learning improves through virtual access to real-time and historical watershed data.

Keywords: hydrology education; environmental monitoring; enhanced student learning; virtual learning

1. Introduction

In 2008, the US National Academy of Engineering (NAE) announced 14 Grand Challenges in engineering that are awaiting solutions in the 21st century. This list includes the challenge to "Provide Access to Clean Water" [1]. Water is the critical element for supplying food and energy, safeguarding human health, and maintaining national security. Increasing pressures for water demand worldwide present challenges to scientists and engineers to attain sustainable management of water resources. A recent United Nations report projects that virtually every nation will face a water supply problem within the next 20 years. It is also estimated that currently more than a billion people have little access to clean drinking water and that 2 billion live in conditions of water scarcity [2]. The recent NAE publication entitled "The Engineer of 2020" emphasizes that water supplies will affect the future of the world's economy and stability. Further, the report highlights the need for implementing ecologically sustainable practices to preserve the environment for future generations [3]. To face large-scale environmental challenges in the 21st century, the National Research Council outlined the need for fundamental knowledge of: (i) the sources of contaminants and how they are linked to different types and levels of human activities; (ii) the persistence, transport processes, and degradation mechanisms of these contaminants; and (iii) the risks they pose to the environment and humans [4]. Schnoor warns in a 2008 NAE magazine article [5] that unless better ways to protect and improve water supplies are found, the future looks dire for billions of people.

A key component to any solution is to educate our youth about critical hydrology related issues, and to train them as future professionals who will develop appropriate solutions to address these challenges. Hydrology education plays a fundamental role in developing professionals who understand critical components of the hydrologic cycle and the impacts that humans have on our water resources. To develop students that are equipped to handle the challenges of the future, classrooms must focus on student-centered approaches that engage the students in hands-on activities [6]. Two of the greatest challenges facing hydrology education in the 21st century include providing student-centered activities and field experiences in the classroom, and replacing historical stationary data with real-time, dynamic, and temporally and spatially variable hydrologic systems [7–8]. Replacing traditional teaching methods with student-centered experi-

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ences will require advances in classroom tools and teaching methods that capture the attention of students through an active learning experience.

As part of an ongoing NSF/TUES (type I) project at Virginia Tech (VT), a Learning Enhanced Watershed Assessment System (LEWAS) lab has been employed to improve water sustainability education in university and community college classrooms. The LEWAS is a watershed monitoring lab on the VT campus that measures water and weather parameters in real-time at high-frequency temporal intervals and distributes this data through an online watershed education tool called the Online Watershed Learning System (OWLS). The educational aim of the lab is to enhance student learning by incorporating LEWAS-based, hands-on activities into the curriculum that engage the students in active and cooperative learning while supporting classroom goals. The LEWAS was implemented into a senior level hydrology course (CEE 4304) at VT in the fall 2012 semester (Year 1) [9] and spring 2014 semester (Year 3), and was implemented into two freshman level courses (EGR 120 intro. to Engineering and EGR 124 Intro to Engineering and Engineering Methods) at Virginia Western Community College (VWCC) in the spring and fall 2013 semesters (Year 2) [10]. The overarching goal of this study is to examine how the LEWAS impacts student learning through active and collaborative learning modules that engage students in water-related hands-on activities both within and outside of the classroom

This paper covers the details of the overall design, implementation, and assessment results from the LEWAS modules impacting more than 60 seniors at VT and 90 freshmen at VWCC. Section 2 of this paper provides the historical background of the LEWAS lab and demonstrates how this lab helps implement the research-to-practice innovation cycle at VT. The theoretical framework on which the engineering education research in this paper is built is discussed in Section 3. Section 4 presents the methodology of implementing real-time, high-frequency environmental data into university and community college engineering education as well as a multi-loop feedback and assessment process that improves student-centered classroom modules and assessment methods. Results in Section 5 indicate that LEWAS modules, which engage students in active and cooperative learning through hands-on classroom and field activities, improve student learning. A pilot test of the OWLS, an online educational tool where students can access real-time data, virtually explore the watershed, and examine case studies, has also produced results that indicate that student learning improves through virtual access to real-time and historical watershed data.

2. The Learning Enhanced Watershed Assessment System (LEWAS)

The development of the LEWAS lab began in 2008 with partial support under an NSF Department-Level Reform (DLR) project (2004–09) at VT. The lab was then called the LabVIEW Enabled Watershed Assessment System (LEWAS) since it represented a research extension of LabVIEW learning modules implemented into a freshman engineering course within the College of Engineering (CoE) at VT [11–12]. Since LabVIEW is replaced by Raspberry Pi as the data acquisition and processing hardware/software, we decided to change the lab's name to the Learning Enhanced Watershed Assessment System (LEWAS) beginning in May 2014. The lab has been integrated into courses across multiple departments including Engineering Education (EngE), Civil and Environmental Engineering (CEE), and Geosciences, reaching over 5,000 students since 2009 at VT [9–10, 13–14]. Prior studies involving the LEWAS lab have revealed that giving students access to real-time watershed data increases student motivation. For example, in a study involving 150 engineering freshmen at VT in the spring of 2012, it was demonstrated that giving students access to real-time water and weather data improved students' motivation to learn about water sustainability issues [13].

The formation of the LEWAS lab is a good example of how engineering education research in EngE informs the educational practice in CEE at VT. In this context, the development of the LEWAS has followed the innovation cycle of educational practice and research [15] as shown in the diagram in Fig. 1. Block 1 illustrates implementation of the LabVIEW modules into a freshman engineering course (Engineering Exploration, EngE 1024) offered by EngE that all freshmen (~1,600 each year) at VT are required to take during their first semester. Positive learning outcomes from the LabVIEW modules led to additional hands-on activities that leveraged the data acquisition (DAQ) strength of the LabVIEW software and introduced students to water related issues on the VT campus by accessing water data using sensors and DAQ features of LabVIEW [11–12]. This ultimately led to the development of the LEWAS lab (block 2) as a system that provides students with a real world application of LabVIEW. Out of this project came a PhD dissertation that demonstrated the educational value of the LEWAS data using the theoretical foundation of the expectancy value theory of motivation (block 3) [13, 16]. In order to expand the application of the LEWAS beyond EngE, the 3rd author collaborated with the 4th and 5th authors and their team won a NSF/TUES (Type I) grant in 2012 that led to

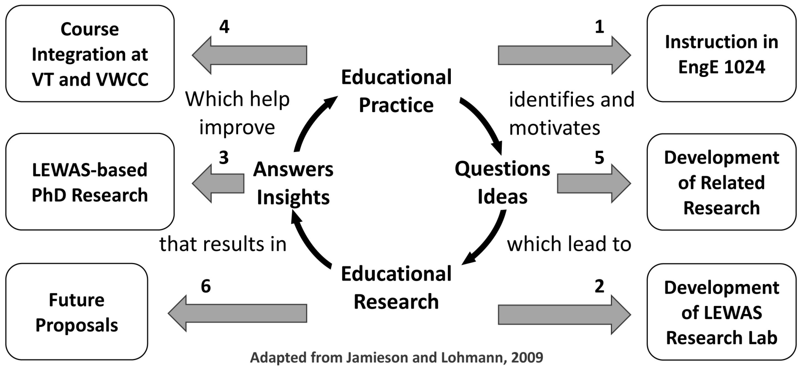

Fig. 1. Innovation Cycle of Educational Practice and Research (adapted from Jamieson and Lohmann, 2009).

incorporation of the LEWAS into a senior level hydrology course at VT (fall 2012 and spring 2014) and two introductory engineering courses at VWCC (fall and spring 2013) (block 4). The implementation of the LEWAS modules into these courses led to further research questions that ultimately resulted in development of the OWLS [17], part of an ongoing PhD dissertation in EngE, which was pilot tested in the spring 2014 hydrology course (block 5). Promising results highlighted in this paper have also led to future research ideas and proposals (block 6) involving the LEWAS lab.

The LEWAS lab is positioned to capture water and weather data in an environmentally significant location on the VT campus. The LEWAS field site is located at the outlet of the Webb Branch within the Stroubles Creek watershed, just upstream of a retention pond known as the Duck Pond. The watershed has an area of 2.78 km^2 and is highly urbanized with residential and commercial development encompassing portions of the Town of Blacksburg and VT campus (Fig. 2). These conditions enable the lab to study the quick response times of a small urban watershed using real-time, high frequency resolution (0.1–3 minute sampling intervals) water and weather monitoring equipment. Webb Branch was chosen as the site of the lab because of its location on the VT Campus and its environmental significance, as Stroubles Creek was found to have a benthic impairment for 8 km starting at the outfall of the Duck Pond retention facility, immediately downstream of the LEWAS site. The stream was 303 (d) listed as impaired by the Virginia Department of Environmental Quality (VDEQ) beginning in 1996 to the most recent report in 2012 [18], and stressors of the stream include sedimentation, urban pollutants, increased development, and stream channel modifications [19].

The instrumentation at the LEWAS site is composed of a network camera and environmental sensors that monitor water quality, flow, and weather parameters (Fig. 3). The sensors and their data collection specifications are given in Table 1.

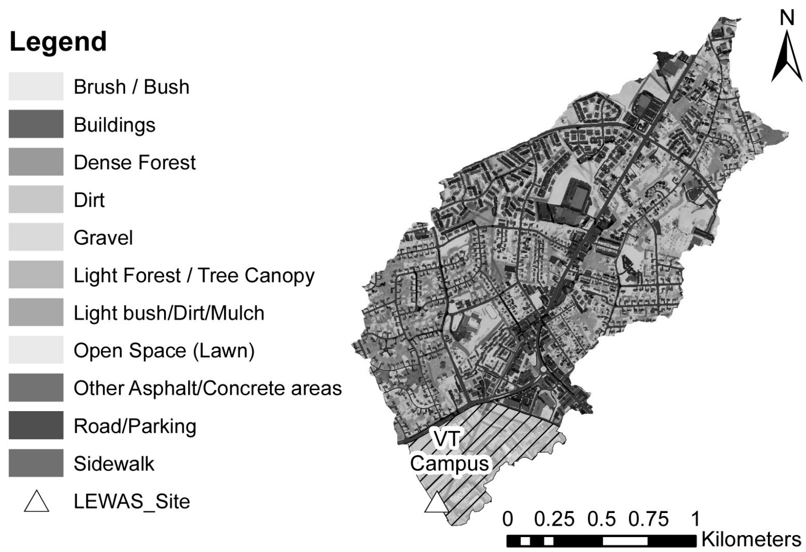

Fig. 2. LEWAS Watershed and Land Use.

Table 1. LEWAS Sensors

Name	Type	Parameters	Sampling Interval
Sontek Argonaut-SW	Acoustic Doppler Current Profiler (ADCP)	velocity and stage for flow estimates	1 minute
Global Water 705	Ultrasonic level transducer (ULT)	stage behind a weir for flow estimates	1 minute
Hydrolab MS-5	Multi-parameter water quality Sonde	pH, temperature, specific conductance, oxidation reduction potential (ORP), dissolved oxygen (DO), turbidity	3 minutes
Vaisala WXT520	Weather transmitter	air temperature, barometric pressure, relative humidity, precipitation*	5 minutes, *instantaneously
Weathertronics Tipping Bucket	Rain Gage	precipitation	instantaneously

Data from the three environmental sensors are collected using a Raspberry Pi computer that runs custom software developed for each sensor (Fig. 4). The sensors are connected to the Raspberry Pi through underground conduit that runs from the sensors to the primary control box. As data is collected by the Raspberry Pi, it is transmitted through the campus wireless network to a local database that in turn stores and transmits it to a live data-viewer within the OWLS. The system is powered by two solar panels that charge two 12 Volt, 30 Amp Hour deep cycle batteries connected

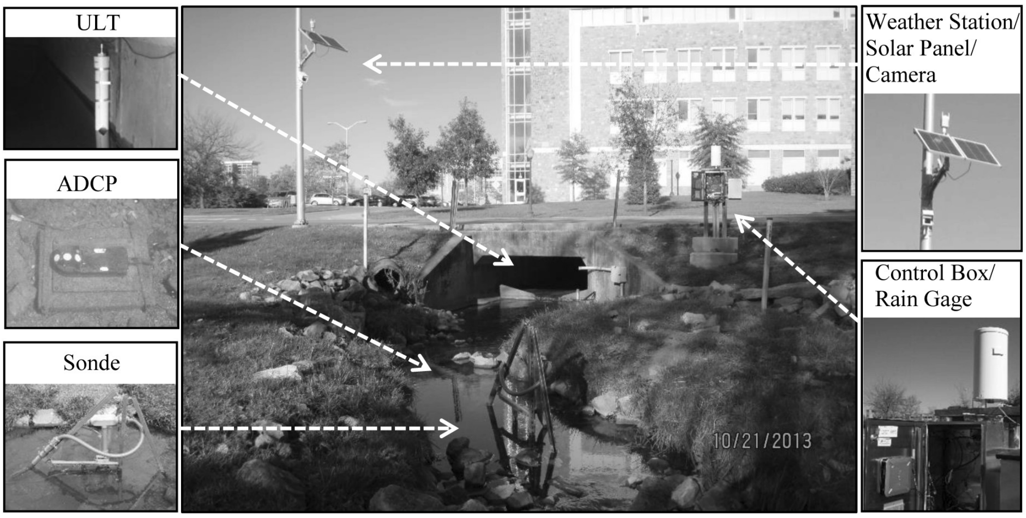

Fig. 3. LEWAS Lab Physical Layout.

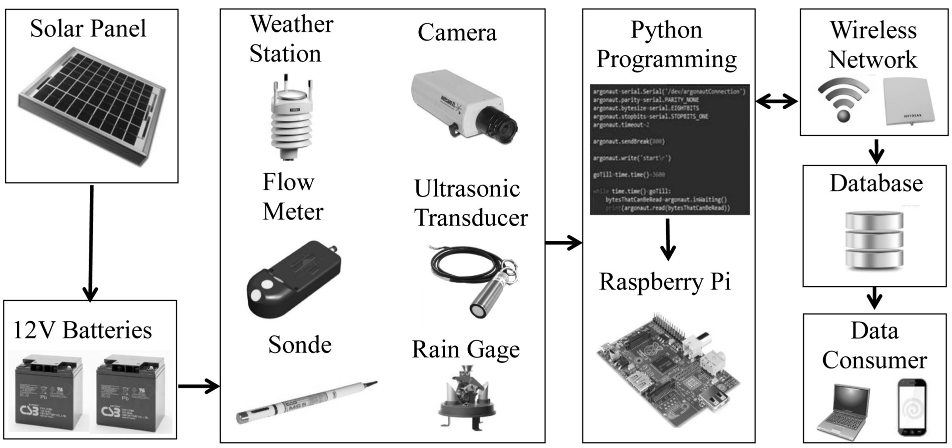

Fig. 4. LEWAS Lab Connectivity (http://www.lewas.centers.vt.edu/).

in series. The batteries, located in a metal housing next to the primary control box, power the instrument operation and data transmission 24 hours a day.

The historical and live data from the LEWAS is made freely available through the OWLS, which acts as the front end of the LEWAS lab. The OWLS was developed during the 2013–2014 academic year and was introduced as a pilot study in the spring 2014 hydrology course. The OWLS uses an HTML5-driven web-interface to deliver integrated live and/or historical remote system data (e.g., visual, environmental, geographical, etc.) to end users regardless of the hardware (e.g., desktop, laptop, tablet, Smartphone, etc.) and software (e.g., Windows, Linux, iOS, Android, etc.) platforms used. One of the strengths of such a design is the idea of anywhere, anytime access to live system data. Another strength is the graphical and visual integration of the data that virtually situates the user at the remote measurement site.

3. Theoretical framework

3.1 Student-centered learning

The LEWAS-based modules promote student-centered activities through active and collaborative learning methods. Active learning is a theory that proposes that students learn most effectively when they are engaged in the learning process by doing meaningful activities that require them to think about what they are doing. Active learning both introduces student activity into the traditional lecture method and promotes student engagement [22]. Studies have shown that students who are interactively engaged through hands-on classroom activities learn and retain more information [23]. Through activities in the classroom, active learning methods promote thoughtful engagement that center around important learning outcomes. LEWAS course module development strategies are based on active learning theories that increase student attention and learning through course designs that keep the student actively engaged in the classroom.

In addition to promoting active learning, LEWAS modules encourage social interactions that promote collaborative and cooperative learning. Collaborative learning refers to any teaching method in which students work together in groups to achieve a common goal [24]. It emphasizes student interactions as central to the learning process rather than learning as a solitary activity and creates classrooms that are student-centered where students take a more active role in their own learning. Cooperative learning is a specific collaborative learning method where students not only work together in groups, but must rely on each other to accomplish shared learning objectives while also being assessed individually [25]. Collaborative and cooperative learning methods are supported by various learning theories [26]. Social interdependence theory views cooperation as a result of positive interdependence among individuals in a group [27]. Individuals in a group are each important parts of a whole and how they interact determines the groups' outcomes. If the interdependence is positive, individuals will encourage and facilitate one another's efforts to learn, if it is negative, they will discourage and obstruct each other's efforts. Cognitive-developmental theory views cooperation among individuals as essential to cognitive growth [28]. This theory suggests that learning will occur in a group if members properly coordinate individual perspectives to attain a common goal. Close work between students and their peers in a cooperative effort, to learn, understand, and solve problems, will result in cognitive development and intellectual growth. The LEWAS seeks to implement student-centered teaching modules based on these sound learning theories by using cooperative and collaborative learning techniques that foster positive group interactions.

3.2 Blooms taxonomy

In its report on the Challenges and Opportunities in the Hydrologic Sciences, the National Academy of Sciences states that, "Ensuring clean water for the future requires an ability to understand, predict and manage changes in water quality" [1]. These three abilities can be aligned with the levels of Bloom's revised cognitive taxonomy [29–30]. *Understanding*, as evidenced by an ability to explain the occurrence of changes in water quality, fits with the second level of this taxonomy i.e., understanding. *Predicting* what is going to happen as the result of a particular event in a watershed fits with the fifth level of this taxonomy, i.e., evaluating. *Managing* requires the development of management plans for a watershed which necessitates the synthesis of diverse factors impacting this system. This ability fits with the top level of the revised taxonomy, i.e., creating. As students' progress through various academic levels, they should likewise advance through all six levels of cognition. Having a high level of cognition about such water systems allows individuals to move beyond solving water sustainability problems to defining water sustainability problems, which allows them to effectively manage water systems [31].

The research design in this paper seeks to assess students' learning of critical hydrology topics. Using Bloom's revised cognitive taxonomy as a

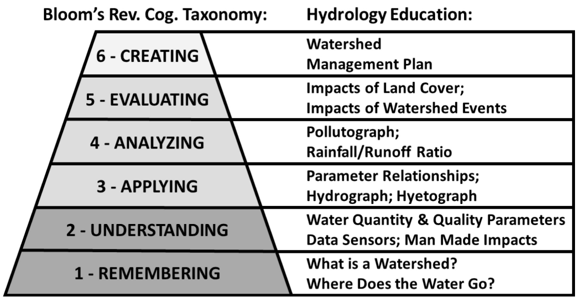

Fig. 5. Lesson plan guide including examples of water sustainability education topics appropriate for each level of Bloom's revised cognitive taxonomy. Examples of the Hydrology Education topics are covered in sections 4.3.1 and 4.4.1.

guide, Fig. 5 suggests topics that are appropriate for each course level and can be used to help students learn these topics. Levels 1–2 are applicable to freshman-level community college courses. Here students are (1) remembering concepts like what is a watershed, and where does its water go, and, (2) understanding topics such as water quantity and quality parameters, data sensors, and human development impacts on a watershed. Levels 3–5 are applicable to the senior level hydrology course. At this level students are (3) applying what they know such as water flow represented as a hydrograph and precipitation represented as a hyetograph, (4) analyzing data such as in computing runoff to rainfall ratios, and (5) evaluating problems such as the impacts from land cover changes and different watershed events. The highest level, (6) creating, is more applicable to a graduate level course where students use their knowledge to create watershed management plans.

3.3 Virtual learning environments

It has been demonstrated that students learn more about the environment they are studying if they have the opportunity to connect classroom learning to experiences in that physical environment through experiential learning [32]. These experiences that bring about associations between the classroom and the real world can be a combination of physical field visits and virtual field visits. Whereas many of the modules in this study include physical site visits for the student, the OWLS virtually situates the users at the field site through an interactive watershed exploration experience. This fits under the framework of situated learning, which argues that knowledge is "distributed among people and their environments" [33–34]. This definition divides situated learning into two primary areas, i.e. knowledge is distributed across people, e.g. a community of practice [35], and knowledge is dependent on the learning environment [36]. The former follows the sociocultural tradition, while the latter follows the sociocognitive tradition [37]. While no two learning environments are exactly alike [38], we are able to make judgments about the best previously learned knowledge to apply to new learning environments based on common features [39].

According to Newstetter and Svinicki, "Effective learning environments support the learner in developing an ability to integrate the external environment structures and internal knowledge in problem solving" [40]. Graphs and images are types of data representations that engineers often use to help them understand systems, and these representations are increasingly being communicated via digital technology. Within the context of water sustainability, technology advances have increased our ability to integrate remotely sensed environmental data into the learning environment [41]. The ways in which physical objects and data representations alter the learning environment is called mediation [37]. One of the strengths of the OWLS is its ability to interactively integrate graphs and images in order to virtually situate users at the LEWAS field site. In this way, the OWLS can be used as a remote lab. Remote labs, which allow users to be situated at the study site without physically being present, are spreading within engineering curricula [42–44]. Additionally, it has been estimated that there will be over 220 million Smartphone users in the U.S. by 2018 [45] and platform-independence allows the OWLS to reach a larger number of people by working across mobile platforms.

Remote labs rely on digital technology to provide remote access to users, and this technology is especially powerful when it is interactive [46]. Multimedia uses digital technology to reach users via multiple types of content, e.g. text, imagery, video and audio. Many types of interactive multimedia can be used in learning, e.g. open-ended learning environments, tutorials and serious games [47]. However, according to Johri et al., "The role of technological tools, particularly digital tools, is extremely under-theorized in engineering education and a perspective of mediation can prove useful to develop a deeper understanding of technology use and design" [37]. They have listed "Empirical studies of mediation by tools used in learning and practice" as a potential engineering learning research topic, which is an excellent match for the OWLS.

4. Methodology

4.1 Goal and objectives

The overarching goal of this study is to examine how the LEWAS impacts student learning through active and collaborative learning modules that engage students in water-related hands-on activities both within and outside of the classroom. The objectives to meet this goal are to:

1. Create and implement student-centered learning modules for a university senior level hydrology course and community college freshman level introduction to engineering courses.
2. Develop and implement tools to assess student learning in each course over the span of three years through a multi-loop assessment approach.
3. Pilot-test application of the OWLS in the Hydrology course in order to assess its impact on student learning.

4.2 Assessment and evaluation procedures

The goal of the assessment approach is to support the research goals that seek to determine how student learning is impacted by LEWAS-based modules. The assessment approach followed a looped process [48–50] that occurred in four phases: (1) planning of the assessment methods based on the desire to improve student learning using LEWAS-based modules, (2) implementing the assessment plan, (3) analyzing and interpreting the data collected, and (4) using the results to improve LEWAS modules and the assessment process. This method, applied across two institutions (i.e., VT and VWCC), created a multi-looped process where the two institutions (university and community college) learned from and informed one another by sharing assessment data (Fig. 6). By following a looped process, the assessment not only provides information on how LEWAS modules improve student learning, but also informs future assessment activities. Thus, assessment results from year 1 were used to improve upon LEWAS modules and assessment methods implemented in year 2, and results from year 2 led to improvements for year 3.

The assessment plan used a sequential triangulation mixed-methods design [51–52] that included both quantitative and qualitative assessment methods in order to develop an understanding of trends in the overall student population as well as to obtain detailed information about student perceptions of participating in LEWAS modules. The mixed-methods approach was developed in a way that offered the best chance to obtain useful results related to the research objectives. Data triangulation was deployed through various quantitative and qualitative methods and data sources, in order to produce valid, reliable, and trustworthy results.

Each method was chosen to be complementary to the other by offsetting weaknesses in the methods or data sources of each approach [53–54]. The quantitative data was collected through pre- and post-tests as well as in-class assignments. Qualitative data was collected through pre- and post-tests, in-class assignments, class blogs, and informal discussions. The quantitative data gives an objective representation of the class population, allowing for inferences on the effectiveness of meeting the stated research objectives. On the other hand, qualitative data takes a more inductive approach, allowing for in-depth answers that can be analyzed without preconceptions or pre-determined categories. Taken together, the quantitative and qualitative data complement each other, producing detailed explanations to generalized data by comparing the results of each.

Some of the qualitative questions were also "quantitized" by applying a framework of categorization to identify themes or categories of responses to open-ended questions [55–57]. The qualitative responses from the assessment questions were quantitized by enumerating the frequency of themes within the sample responses. This allows the qualitative data to be statistically compared to the quantitative data and for the identification of whether or not qualitative responses contain certain themes. Themes were extracted using NVivo software and two different investigators to ensure inter-

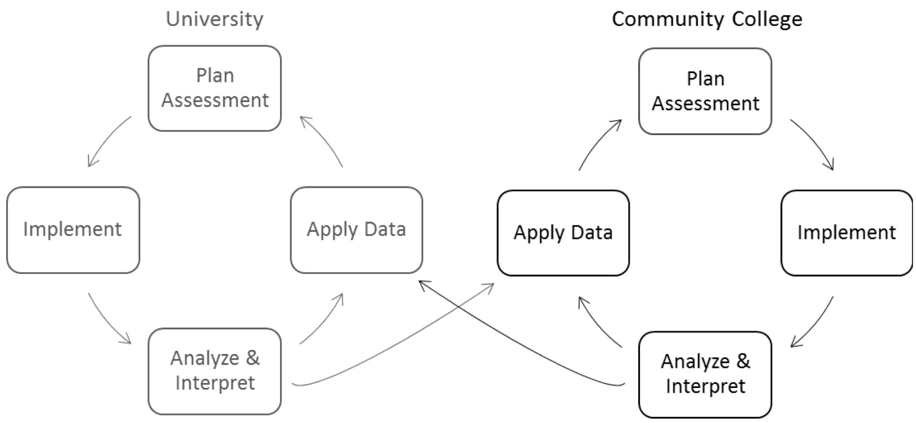

Fig. 6. Multi-looped Assessment Structure between the University and Community College.

rater reliability of the assessment instruments, resulting in an average Cohens kappa coefficient of 0.8 [58–59].

Student assessment was collected through three methods: (1) pre- and post-tests, (2) class assignments, and (3) informal discussions. The pre- and post-tests were given to students before and after LEWAS based modules were implemented in their respective courses. To establish content-related validity [58], experts in hydrology and water quality developed the pre- and post-test questions to assess student learning related to the course objectives and ABET a-k student outcomes [60]. The pre- and post-tests contained a mix of concurrent quantitative and qualitative questions including categorical, ordinal, numerical, and discussion questions. In addition to pre- and post-tests, students were given assignments in class that asked them to use the LEWAS system to answer homework questions directly related to classroom objectives and to reflect on their experiences. These assessments provided quantitative information from student responses to specific questions that require quantitative or categorical answers. Some questions in the assignments were qualitative and designed to provide detailed responses that further describe quantitative findings. Some students in the 2014 Hydrology course (Year 3) also shared their experiences through informal discussions after class. These discussions sought to gain thick descriptions from students related to their experiences using the LEWAS.

Taken together, the student assessment data sources are designed to give a good representation of the overall student experiences and learning outcomes from implementation of the LEWAS modules. Figure 7 illustrates the assessment procedure for year 3. The multi-looped assessment procedure led to the development of improved assessment methods throughout the study. In years 1 and 2, the assessment focused only on the pretest, posttest, and class assignments. However, results that provided thick descriptions of the student experience and detailed activities were lacking in the data. In order to obtain deeper insight into the student experience, informal discussions were added in the final year. Results from the assessments are provided in sections 5.1–5.3.

There are multiple limitations that should be considered given the experimental design. The design is subject to internal validity threats due to history (i.e., an event could occur during treatment that influences the outcomes), maturation (i.e., participants could mature or change throughout the treatment thereby influencing the results), testing (i.e., the pretest could cause the participants to become familiar with the material), selection (i.e. students in the class will not be randomly selected but are chosen due to accessibility and resource constraints) or interaction effects through a combination of threats [61]. In addition, non-random sampling may introduce systematic errors such as selection bias, which undermines the external validity of the assessments. The samples will contain students from the same course and will not be statistically representative of a greater population, therefore limiting the generalizability of the results.

4.3 Hydrology course at VT

The LEWAS was implemented into a senior level hydrology course at VT during the fall 2012 and spring 2014 semesters. Hydrology is an elective course for senior and graduate students and is taught once per year with an enrollment between 30 and 70 students, approximately 10% of whom are graduate students. The course covers the fundamentals of hydrology including basic issues and mechanisms of precipitation, infiltration, evapotranspiration, runoff, and subsurface flow, and accompanying computational methods. Special emphasis is placed on surface runoff quantity generation, including flood routing and forecasting and urban hydrology issues. The primary goal of inte-

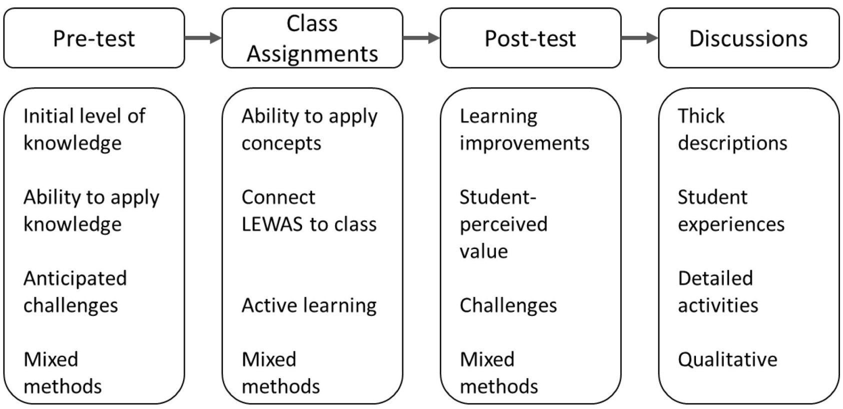

Fig. 7. Sequential Student Assessment Procedure for Year 3 Implementation.

grating the LEWAS into the hydrology course was to enhance student learning by incorporating LEWAS-based active learning modules throughout the semester as the students were learning hydrologic topics. Distinct advantages of implementing the LEWAS in a course on the VT campus are that the students become familiar with the watershed in which the classroom is located, and students have direct access to the field site located on campus.

4.3.1 Hydrology learning modules

The LEWAS was introduced to the students with a presentation at the beginning of the course that covered the outdoor lab and its components, the watershed, and the purpose of monitoring the stream. Table 2 presents the LEWAS hydrology learning modules that were implemented into the hydrology courses. For the spring 2014 Hydrology course implementation, three additional modules (Storm Data Water Quality Analysis; Flow Computations; Soil Saturation Impacts) were created to further capitalize on the LEWAS' capabilities to reinforce hydrologic concepts. These additional modules were motivated by the assessment results from fall 2012 implementation in year 1 as well as implementation of the LEWAS into VWCC curriculum in year 2.

In addition to the new modules, students were given an OWLS-based assignment near the end of the course as a pilot implementation of the educational tool. Students were required to use the OWLS over the course of a week and answer questions related to environmental data, graphical representations, case studies, and other observations. During this week, students were given access to historical data that was incrementally added to the OWLS to give the appearance of being live. A screen shot of the single graph view within OWLS in Fig. 8 gives an example of the data that students used throughout the week. This allowed the students to use the OWLS during a simulated week of data that had multiple watershed events captured by pictures and flow, water quality, and weather data. Details of the OWLS development can be found in previous works [17, 63].

These modules and activities required the students to engage in multiple higher levels of cognitive thinking as related to Blooms taxonomy. Students are required to apply (level 3 Blooms) what they learn in class, such as hydrographs and hyetographs, to multiple problems involving LEWAS data. The modules also require students to analyze (level 4 Blooms) the LEWAS data, such as computing storm flows and testing runoff/rainfall ratios. Finally students are required to evaluate (level 5 Blooms) their results in a greater context, such as discussing how land cover or the factors surrounding a rainfall event affect the runoff/rainfall ratios.

4.4 VWCC courses

The LEWAS modules were implemented into one freshman level introduction to engineering course at

Table 2. Hydrology Learning Module Descriptions

Module Title	Content	Objective	Student Assignment
Storm Characteristics	hyetographs, hydrographs, land cover, abstraction	Give students experience with LEWAS data	Compute rainfall-runoff coefficients with LEWAS rainfall and flow data
Land Cover—Peak Flow—Water Quality Correlation	land cover, storm flow quality and quantity, peak flow rate, runoff coefficients	Understand impact land cover has on water quality	Evaluate runoff coefficients using digitized land cover, comment on error types in runoff coefficients
Watershed Wiki	weather, flow, water quality, data analysis, data quality	Promote active and collaborative learning through hands-on group assignments	Monitor the watershed as a group for a week and write a daily blog on stream conditions and submit a comprehensive report [62–63]
Storm Data Water Quality Analysis	water quantity, water quality, stormwater	Understand the linkages between water quantity and water quality	Students analyze LEWAS data and discuss how certain water quality parameter were related to flow
Flow Computations	flow measurement methods, contemporary flow sensors	Understand different flow measurement methods and techniques	Over a week groups compare their own stage and flow measurements with measurements from LEWAS sensors
Soil Saturation Impacts	antecedent moisture condition, soil saturation, overland flow	Understand the effect that antecedent soil moisture conditions have on infiltration and runoff rates	Students analyze consecutive and standalone storms to calculate the impact of soil moisture on runoff

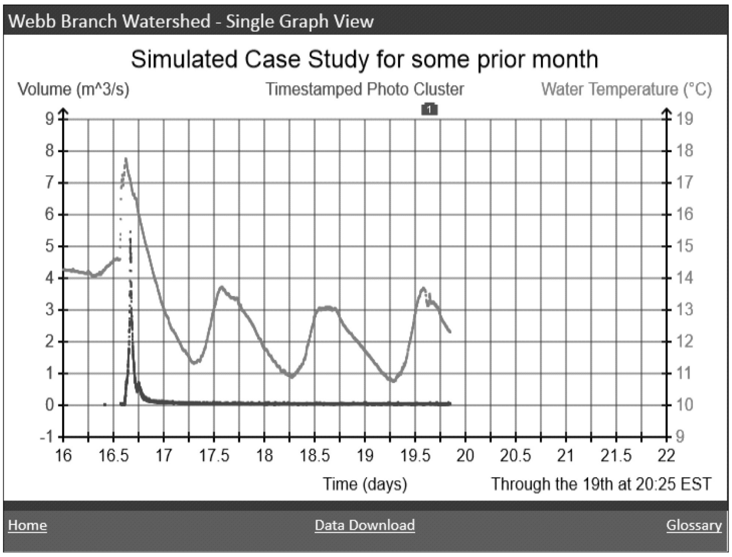

Fig. 8. OWLS Screen Caption of Single Graph View.

VWCC in the spring 2013 semester, and again into two courses in the fall 2013 semester. In total approximately 90 students were exposed to the LEWAS modules at VWCC. Unlike in the Hydrology course where the LEWAS was introduced in modules spread out over the duration of the semester, the LEWAS was implemented into the VWCC courses over a span of 2 weeks (4 total classroom sessions) near the end of the semester. This is due to the structure and content of the freshman-level community college introduction to engineering courses. Whereas the hydrology course has topics throughout the semester that are consistently related to LEWAS data, topics in the introduction to engineering courses are not directly associated with hydrologic data. In EGR120, students are introduced to the basics of engineering including statistical analysis and LabVIEW programming, and in EGR 124 students are introduced to the engineering calculations, worksheets, and elementary numerical methods. The LEWAS effectively addresses these course topics in a two week module by providing real-world engineering problems and an application of LabVIEW programming. The implementation of LEWAS into these courses illustrates the multidisciplinary nature of the LEWAS in that it can be applied to courses that are outside of hydrology education but that still deal with programming and data.

Multiple seminars and workshops were held to develop VWCC LEWAS sessions and train VWCC instructors in the LEWAS system. Seminars were held in fall 2012 and spring 2013 to train VWCC instructors in critical components of the LEWAS including the sensors, data, and hydrologic concepts. These seminars also resulted in initial discussions that led to the development of the LEWAS module for VWCC classes. In addition, VT team members visited VWCC to assist in the pilot implementation of the LEWAS module in the first week of the spring 2013 semester. Two workshops were also held in the summers of 2013 and 2014 to discuss the results of the implementation and prepare plans for the coming year. These workshops allowed researchers from VT and VWCC to come together as a team to discuss the previous year's assessment data and to create improvements to the modules and assessment methods for the upcoming year.

4.4.1 Intro. to engineering module

The module was developed to support the class goals and outcomes through a real world application of LabVIEW programming, data acquisition, and data analysis. Specific learning objectives of the LEWAS sessions were to introduce students to a practical application of LabVIEW, problem solving strategies via LabVIEW and Microsoft Excel software, hands-on data collection, hand calculations and unit conversions, basics of water quality monitoring, water sustainability, and ethics. Description of the sessions including the content, objectives and student assignments of each are shown in Table 3. Sessions from the spring to the fall semester remained relatively constant with minor changes in the homework and in-class assignments as a result of student feedback from the assessments and the availability of new data captured by the LEWAS.

These modules required students to engage at the multiple cognitive levels outlined in Blooms taxonomy. Students were challenged on their ability to remember an (level 1 Blooms) important watershed concept such as where their water flows and what defines a watershed. Students were also required to understand (level 2 Blooms) their data, where it

Table 3. VWCC Class Session Descriptions

Session Title	Content	Objective	Student Assignment
Watershed Concepts	water cycle, watersheds and runoff, pollution, ecosystem functions	Promote active and collaborative learning through hands-on group assignments	Students test water quality at the Roanoke River, blog about their experiences [65–67], and analyze the data
Stormwater Quality	stormwater Best Management Practices (BMP), flow, weather and water quality sensors, LabVIEW	Introduce students to contemporary watershed sensors and a real world application of LabVIEW	In class exercises with understanding how the LEWAS is connected with LabVIEW
Data Analysis I	flow rate, pollutant concentrations, pollutant loads, runoff ratios	Use data analysis to understand what goes on within a watershed	In class exercises computing runoff ratios, pollutant loads, watershed area, etc.
Data Analysis II	population statistics, distributions	Use data collected by the class to compute summary statistics	In class exercise computing summary statistics and plotting data time series

comes from, and how it is an indicator of overall stream health. In sessions 3 and 4, students were required to apply (level 3 Blooms) statistical methods they learned in class to the data they collected and then analyze (level 4 Blooms) their results.

5. Results and discussion

5.1 2012 Hydrology (Year 1)

The 2012 Hydrology course was the pilot course for LEWAS-based modules, and pre- and post-test assessment questions were focused on understanding students' perceived usefulness of the modules and recommended improvements. Table 4 contains a sample of the pre- and post-test questions that directly correspond with each other, along with results and example responses. Overall results indicated that the majority of students found the LEWAS modules to be useful in understanding hydrologic concepts, and recommended that the LEWAS be included extensively in future hydrology courses.

To understand what difficulties students would experience in implementing LEWAS classroom modules into the course, students were asked in the pre- and post-tests what challenges they expected and what challenges they faced in completing the assignments. Students in the pre-test cited their biggest concern in understanding the data (39%), followed by bad weather (27%). However, in the post-test only 8% of the students cited a lack of understanding, and no students mentioned challenges with bad weather. These results suggest that students in the beginning of the course lacked self-efficacy or confidence in themselves that they would be able to understand the data. However, as indi-

Table 4. Fall 2012 Hydrology Pre-test and Post-Test

Pre-test (n = 26)	Post-test (n = 26)
How can this system help you learn hydrologic concepts? *Real time data (23), Monitoring events in the watershed (3)*	How did this system help you learn hydrologic concepts? *Real-world data (23), Not useful (3)*
How can this system help educate you about sustainable development? *"It will give insight into how development effects water quality, and how to avoid adverse effects"**	How did this system help educate you about sustainable development? *"It helped me understand how development does affect downstream areas"**
What difficulties can you anticipate in your one week assignment to monitor the water quantity, quality and weather parameters? *Understanding data (10), Bad weather (7), Lack of live data (3), Unknown variations in data (2), Availability for site visits (2), Lack of rain (2)*	What difficulties did you experience in your one week assignment to monitor the water quantity, quality and weather parameters? *Availability for site visits (5), Unknown variations in data (4), None (4), Visual assessments (3), Lack of rain (3), Errors from debris (2), Understanding data (2), Crossing Street (1), Lack of live data (1)*
How can this system be used for advancing research questions relevant to hydrology? *"This system will greatly benefit hydrology because it provides a way to quantify and record parameters of a stream in real time"**	How can this system be used for advancing research questions relevant to hydrology? *"This system can be used to identifying some of the major causes to change in water quantity and quality"**

* Example Response.

cated by post-test responses, most of these students did not have challenges understanding the data. As a follow-up question, students were asked how their difficulties differed from the difficulties they anticipated experiencing. The majority of student responses indicated that they were unsure of what to expect since the system, data, and concepts were new to them. Others mentioned that in the beginning they expected that they would not be able understand the assignments. For example, one student stated "I was expecting that we wouldn't be able to interpret the reason for changes in the data provided." This indicates that the students were able to not only understand the data, but also interpret the meaning behind LEWAS data, a primary desired outcome of the LEWAS modules in the hydrology course.

During the *Watershed Wiki Module*, students began to understand the interactions and behaviors of the stream before ever looking at the data. In student blog posts, most students were able to describe the relationships between their own observed conditions in the stream and what in the watershed caused those conditions. For instance, one group wrote, "The water was clear with no oily sheen, but there were some bubbles and foam present, potentially a sign of pollution caused from runoff from the adjacent parking lots." Another group was able to connect the high water temperature in the stream to runoff from hot parking lot surfaces in the watershed. By making these connections before seeing the data, students are better able to make sense of the data that they see from the LEWAS sensors and provide reasons for trends in the data.

To assess the student-perceived value of the system, students in the post-test were asked what value they saw in real-time monitoring of water quantity and quality data. The majority (67%) stated that real-time monitoring was useful for assessing the effects of various inputs into the watershed, followed by the use of real-world data in the classroom (17%), and the use of data for water quantity and quality monitoring (17%). These results indicate that students understood the need for real-time data to capture events that may occur in the watershed due to human induced effects and the value that this has for research and education.

Overall results from this assessment indicated that students were able to understand important hydrologic concepts through the LEWAS modules. These results were used to improve assessment questions and inform future module development in the following years. Additional information specifically on how high-frequency data improved student learning in the fall 2012 Hydrology course can be found in McDonald et al. [10].

5.2 2013 VWCC (Year 2)

Year 1 demonstrated how hands-on modules helped senior level students learn important hydrologic concepts. Considering the assessment data and feedback received from year 1, a similar assessment and hands-on module development approach was taken for the VWCC courses in year 2. The goal of the assessment was to determine how this system improved student learning through active and collaborative learning modules. Table 5 contains a sample of the pre-test and post-test questions that directly correspond with each other, along with results and example responses from the spring and fall 2013 classes. Results indicated that students in these courses were able to understand, apply, and synthesize the data.

To assess students' understanding of the spatial difference between the LEWAS watershed and the Roanoke watershed where their college was located, students in the pre- and post-test were asked where the water in the Roanoke River and in the LEWAS site ultimately drains to. Acceptable answers for where the Roanoke River ultimately drains to improved from 57% of student responses in the pre-test to 74% in the post-test. Similar results were seen for a question asking where water flowing at the LEWAS site ultimately drains to with an increase of 36% of acceptable student responses in the pre-test to 85% in the post-test. Improvement in student responses to these questions reveals that the modules improved the students' recollection of where their rainwater drains to and of their local water cycle.

A desired outcome of these modules was for students to be able to understand what effects humans have on our water resources. Students were asked to comment on how this system helped them understand the effects of man-made activities on water quality and quantity in a watershed. The majority of responses in the pre-test were general and commented on how the system will help them to understand what impacts humans have on water quality. One student stated that "*it can help us learn about the long-term effects of man-made activities by analyzing data*." In the post-test responses the majority of students went from a general answer to more specific examples such as "*from the data we collected I was able to infer that things such as construction runoff and erosion had an effect on the living organisms*", and "*I learned the negative impacts of pollution and runoff due to paved areas surrounding creeks, streams and rivers.*" The responses demonstrate that students were able to take what they learned in class, along with the data that they analyzed in the modules, and draw specific conclusions as to

Table 5. Community College Spring and Fall 2013 Pre-test and Post-test

Pre-test (n = 73)	**Post-test (n = 54)**
The water flowing in the Roanoke River ultimately drains into *Atlantic Ocean (42)*	The water flowing in the Roanoke River ultimately drains into *Atlantic Ocean(40)*
The water flowing at the LEWAS Site (Blacksburg) ultimately drains into *Gulf of Mexico (26)*	The water flowing at the LEWAS Site (Blacksburg) ultimately drains into the *Gulf of Mexico (46)*
How can this system help you learn the effects of man-made activities on water quality and quantity in a watershed? *"By monitoring the measurements over a period of time, the measurements can be used to interpret the effects of activities of how that relates to water quality and quantity"**	How did this system help you learn the effects of man-made activities on water quality and quantity in a watershed? *"The man-made activities made real, measureable differences in the water quality in our watershed. These differences can have a huge effect on organism survival."**
How can this system help educate you about sustainable development? (Sustainable development is defined as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" *"So we can learn how to properly use the watershed without destroying it for future generations to come"**	How did this system help educate you about sustainable development? (Sustainable development is defined as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" *"I learned there are many ways that have been developed to lower the amount of runoff in urban areas."**
What difficulties do you anticipate in your two week assignment to monitor the water quantity, quality and weather parameters? *Scheduling (13) Weather (17), Lack of Understanding (3), Equipment (1), Quality of Data (5), Unknown (15), None (3)*	What difficulties did you experience in your two week assignment to monitor the water quantity, quality and weather parameters? *Weather (24), Scheduling (15), Lack of Understanding (1), None (3)*
How can this system be used to educate the public (who won't have your hands-on experience) about sustainable development? *"It can be used to educate the public about how are human activity can affect the water quality and how that effect the future generations."**	How can this system be used to educate the public (who don't have your hands-on experience) about sustainable development? *"We can use the data we collected to show how certain things effect the ecosystem."**

*Example Response.

how man-made infrastructure and development affects water quality.

To determine if students could take what they learned and apply it to another concept, students were asked to comment on how this system could help (pre-test) or did help (post-test) educate them about sustainable development. Throughout the modules, sustainable development, defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs", is not explicitly addressed in reference to the LEWAS system. Thus, students are asked to think more deeply about sustainable development and how they could interpret their LEWAS experience in such a context. In the pre-test, 39% of students indicated that they didn't know how it could help educate them about sustainable development, 31% indicated that it could help in developing some sort of sustainable solutions in the future, and 18% indicated that it could help in understanding effects on the environment. In the post-test 38% of the students indicated that it could help in developing sustainable solutions, 30% cited more specific examples, 17% indicated that it could help in understanding effects on the environment, and 13% indicated that it did not help educate them about sustainable development. More specific examples included one student who stated "*I have learned about permeable pavement to help naturally filter water*", and another who stated "*I learned some of the limits that must be maintained in water*", referring to the United States Environmental Protection Agency (USEPA) regulations. The vast majority (87%) in the post-test were able to make a connection between LEWAS modules focused on watersheds and sustainable development. This demonstrates how students were able to take what they learned and apply that understanding to a contemporary concept.

Another question asked students how the system can be used to educate the public about sustainable development. This required the students to think about how they would teach someone else about sustainable development using this system, now that they had hands-on experience with it. The majority of students responded that the data could be used to educate the public about the health of the watershed. One student noted that "*we can use the data we collected to show how certain things affect the* *ecosystem*" and another stated that it can be used to "*show how our actions really do impact the ecosystem around us*." These students were able to synthesize their experiences and propose their own public education plans.

The student assessment results indicate that students were able to remember important ideas, understand the concepts and data that were presented, apply that data to other concepts such as water sustainability, and synthesize their experiences to propose future action. Although the students were not actually taking their skills learned in the two week module and applying those skills to solve specific problems, they were able to articulate the methods and strategies by which they would apply their knowledge to water sustainability problems and educate others using their experiences.

5.3 2014 Hydrology (Year 3)

Year 1 results indicated that students were able to learn hydrologic concepts using the LEWAS modules and year 2 results demonstrated that freshman level students were able to understand concepts and apply environmental data. What was lacking in the assessment data was in-depth insights into how the LEWAS modules help students learn. Assessment methods in year 3 sought to gain a deeper understanding of how LEWAS modules improved student learning. This was done through additional open-ended questions developed for the pre- and post-tests as well as through informal discussions that provided thick descriptions of the student experience. In addition, another goal was to understand how student experiences with an online interactive watershed exploration tool (OWLS) improved student learning.

Both the pre- and post-test questions asked the students "How can this system help you to learn Hydrologic concepts?" Results indicate that students anticipated that having real-world data would help the most in aiding their understanding of hydrologic concepts (Fig. 9a). However, post-test results show that having access to live monitoring of events in the watershed had the greatest impact in understanding concepts in class (Fig. 9b). One student stated that "*by observing conditions and then watching the data, it helps us understand how weather is related to water data*." This indicates that giving students access to real-time data of watershed events has the greatest impact from a student perspective on helping them learn hydrologic concepts. In addition, three students indicated that data visualization through the OWLS and other LEWAS modules was the most beneficial to them. One student stated that the data visualization helped students learn hydrologic concepts because "*it can show graphically the relationship between precipitation events and flow in streams in a watershed.*"

Just as in the first two years, students were asked in the pre- and post-test what challenges they expected and what challenges they faced in completing the assignment in order to compare what difficulties students expected and actually experienced (Fig. 10). From the pre-test, the majority of students anticipated that their lack of understanding of the equipment, parameters, and system would be the greatest challenge. However, in the post-test, none of the students cited a lack of understanding as a challenge. The results reveal that although in the beginning a large number of students had a self-perception that they would have a difficult time understanding environmental sensors and water quality, none of them in the end recognized this as a challenge. Although typical hydrology classes do

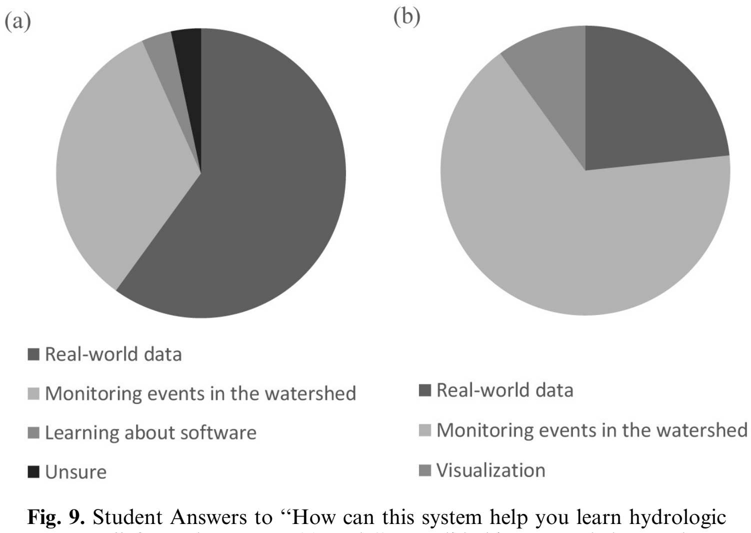

Fig. 9. Student Answers to "How can this system help you learn hydrologic concepts?" from the pretest (a) and "How did this system help you learn hydrologic concepts?" from the posttest (b) (n = 30).

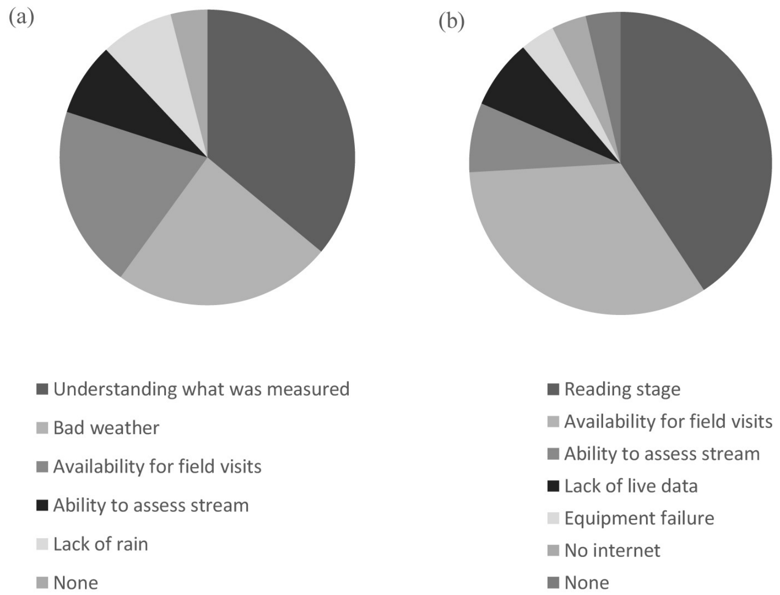

Fig. 10. Student responses to "What difficulties can you anticipate in your one week assignment to monitor the water quantity, quality and weather parameters?" from the pretest (a), and "What difficulties did you experience in your one week assignment to monitor the water quanity, quality, and weather parameters?" from the posttest (b) (n = 30).

not address water, weather, and flow instrumentation or discuss the relationship between water quality and water quantity, these results show that students in this course expressed no problems in grasping these concepts.

In fact, at the end of the course, the majority of students were able to make the connection between water quantity and its effect on water quality. When asked to describe the relationship between pH during and after a rain event, 80% of students in the post-test, as opposed to 32% of the students in the pre-test, indicated that during a rain event the flow would increase and the pH would decrease due to acidity of rainfall and contaminants that runoff into the stream. Enabling students to make this connection and others like it is essential to developing hydrologists that understand the important linkages between water quantity and quality.

In informal discussions, some students described an "aha" moment that gave them new insights into hydrologic concepts. One student defined such a moment as observing a rainfall event and watching the water level rise and then relating that to the hydrograph that they had learned about in class. Another student mentioned being able to visually see the difference in turbidity from a day with clear water to a day when the water was murky and relate what was seen to the difference in the turbidity data. A third student discussed an experience of watching data within the OWLS and seeing a storm event in which water quality parameters changed in a way the student had not thought about before. Each of these experiences enabled the students to relate what they saw in the field to what they were learning in class and to make a meaningful connection between in-class topics and real-world action. Students agreed that being able to see things happen both in the field and through the OWLS helped them to make sense of what they learned in class.

The pre- and post-tests also asked the students questions directly related to their OWLS exercise. The students were asked what they thought is "the added value of the OWLS that delivers live and/or historical remote system data to end users regardless of the hardware and software platforms of their choice." Pre-test results indicated that the majority of students (31%) thought that the greatest value in a system like the OWLS was accessibility. However, after the students had access to the OWLS, this value increased to 80% of students, indicating that the accessibility of the OWLS was of the greatest value. One student stated, "*This allows for widespread application and study by people of various backgrounds and makes the information readily accessible and reduces issues with obtaining the data*." This student recognized that systems such as the OWLS greatly improve accessibility not only to students but to diverse user groups. Other students recognized that the visualization of data was a major advantage of the OWLS environment. One student commented that it was beneficial to be able "*to see trends and analyze changes in the system*", and another student stated that it was valuable to be able to "*view charts/maps/data at any point during your day*." Overall student responses indicated that the OWLS does have added value and that having visual access to data, both real-time and historical, is one of the biggest advantages of a system like the OWLS.

Students were asked other questions to determine if the system was effective at facilitating student learning. To see if students thought that the OWLS had an impact on their learning, students were asked if the OWLS helped them learn hydrology concepts with 97% indicating either "agree" or "strongly agree." This clearly indicates that students, when asked to think about how their learning was impacted by the OWLS, agreed that the OWLS helped them to learn hydrologic concepts in class. In addition, students were asked in their OWLS homework assignment to observe the LEWAS data and describe how precipitation events impact water quality in the stream. Students were able to observe trends in simulated LEWAS data and draw conclusions about the watershed behaviors. For instance, one homework group noted that "*due to a higher dissolved solids concentration introduced into the stream by runoff, the specific conductivity increased to approximately 800* $\mu S/cm$", and another group stated "*The water temperature increased from 58* $^{\circ}F$ *to about 64* $^{\circ}F$ *due to the amount of higher temperature runoff volume flowing into the stream.*" These students were able to make the connection between the data they saw and the reasons for trends that they were noticing. The implications from these results are that access to real-time data through systems such as OWLS can improve student learning and be used to improve hydrology education.

6. Conclusion

This paper has demonstrated how high-frequency, real-time environmental data can be used to improve student learning through student-centered modules at the university and community college level. Furthermore, it demonstrates how engineering education research at VT is impacting educational practice. Results indicate that LEWAS modules that utilize active, collaborative, and cooperative learning methods can be implemented into the classroom to improve hydrology education. Through access to real-time data, students are able to make connections from the classroom to the real-world environment around them. In a pilot study of an environmental watershed exploration tool, the OWLS modules have demonstrated that student access to live data improves student learning. An assessment methodology that utilizes a multi-loop process demonstrates how university and community college institutions can work together to improve assessment methods and module development.

Future work will include student-centered LEWAS modules in future offerings of the hydrology course at VT and the introduction to engineering courses at VWCC. Assessment results from this study have led to improved assessment methods and modules for future courses. Each course will include new modules that utilize the virtual experience of the OWLS to support course objectives. The goal of future modules will be to further understand what effect OWLS access, through a live-data virtual environment, has on student learning. Additionally, the LEWAS will be integrated into VWCC courses as a set of modules throughout the entire semester instead of as a single 2 week module. This approach will take full advantage of the LEWAS data and technologies to further support classroom objectives. Assessment methods will be similar to year 3, but instead of informal discussions there will be a formal focus group led by an assessment expert. In addition, LEWAS use will be expanded into other courses at VT. In fact, a workshop was organized on May 14, 2014 to explore the use of the LEWAS/OWLS into a variety of courses in the Civil and Environmental Engineering, Geosciences, Biological Sciences, and Crop and Soil Environmental Sciences departments at VT. The authors have collaborated with a number of faculty from these departments to develop LEWAS modules for their courses in upcoming semesters.

The importance of training hydrology professionals to solve increasing global water crises has never been greater, and improvement to hydrology education is a critical component in any solution. Systems such as the LEWAS will be essential in improving engineering education at all levels of higher education. Student centered modules that give students access to real-time data enable them to make connections between what is happening in the classroom and the real world. As the need for new ways to improve hydrology education increases, systems such as the LEWAS will play an important role in advancing water education to meet the challenges facing hydrology in the 21st century.

7. Glossary of Acronyms

LEWAS – Learning Enhanced Watershed Assessment System
OWLS – Online Watershed Learning System
VT – Virginia Tech
VWCC – Virginia Western Community College
EngE – Engineering Education
CEE – Civil and Environmental Engineering
DAQ – Data Acquisition
NAE – National Academy of Engineering
DLR – Department Level Reform

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References

1. National Research Council (NRC), *Challenges and Opportunities in the Hydrologic Sciences*, The National Academies Press, Washington, D.C., 2012.
2. United Nations (UN), *Water for People, Water for Life*, UN World Water Development Report, New York, NY, 2003.
3. U.S. National Academy of Engineering (NAE), *The Engineer of 2020*, *Visions of Engineering in the New Century*, The National Academies Press, Washington, D.C., 2004.
4. National Research Council (NRC), *Envisioning the Agenda for Water Resources Research in the Twenty-First Century*, The National Academies Press, Washington, D.C., 2001.
5. J. L. Schnoor, Living with a changing water environment, *The Bridge*, **38**(3), 2008, pp. 46–54.
6. I. Ngambeki, S. E. Thompson, P. A. Troch, M. Sivapalan and D. Evangelou, Engaging the students of today and preparing the catchment hydrologists of tomorrow: Student-centered approaches in hydrology education, *Hydrology and Earth System Sciences Discussion (HESSD)*, **9**(1), 2012, pp. 707–740
7. B. L. Ruddell and T. Wagener, Grand challenges for hydrology education in the 21st century, *Journal of Hydrologic Engineering*, **20**(1), 2013.
8. G. Bloschl, G. Carr, C. Bucher, A. H. Farnleitner, H. Rechberger, W. Wagner and M. Zessner, Promoting interdisciplinary education—the Vienna Doctoral Programme on Water Resource Systems, *Hydrol. Earth Syst. Sci. Discuss.*, **8**(1), 2011, pp. 9843–9887.
9. R. L. Dymond, V. K. Lohani, D. Brogan and M. Martinez, Integration of a real-time water and weather monitoring system into a hydrology course, *Proc. 120th ASEE Annual Conference & Exposition*, Atlanta, GA, 2013.
10. W. M. McDonald, R. L. Dymond, V. K. Lohani, D. S. Brogan and R. L. Clark, Integrating a real-time remote watershed monitoring lab into water sustainability education, *Proc. 2014 ASEE Annual Conference & Exposition*, Indianapolis, IN, 2014.
11. V. K. Lohani, P. Delgoshaei and C. Green, Integrating LabVIEW and real-time monitoring into engineering instruction, *Proc. 2009 ASEE Annual Conference & Exposition*, 2009, Austin, TX.
12. P. Delgoshaei, V. K. Lohani and C. Green, Introducing dataflow programming in a freshman engineering course with applications in sustainability education, *Proc. 2010 ASEE Annual Conference & Exposition*, Louisville, KY, 2010.
13. P. Delgoshaei, *Design and implementation of a real-time environmental monitoring lab with applications in sustainability education*, Ph.D. Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA, 2012.
14. P. Delgoshaei and V. K. Lohani, Design and application of a real-time water quality monitoring lab in sustainability education, *International Journal of Engineering Education*, **30**(2), 2014, pp. 1–14.
15. L. H. Jamieson and J. R. Lohmann, Creating a culture for scholarly and systematic innovation in engineering education, *American Society for Engineering Education*, Washington, D.C., 2009, https://asee.org/retention-project/creating-a-culture-for-scholarly-and-systematic-innovation-in-engineering-education. Accessed 10 July 2015.
16. J. S. Eccles, T. F. Adler, R. Futterman, S. B. Goff, C. M. Kaczala and J. L. Meece, Expectancies, values, and academic behaviors, in J. T. Spence (Ed.), *Achievement and achievement motivation*, W. H. Freeman, San Francisco, CA, 1983, pp. 75–146.
17. D. S. Brogan, V. K. Lohani and R. L. Dymond, Work in progress: The Platform-Independent Remote Monitoring System (PIRMS) for situating users in the field virtually, *Proc. 2014 ASEE Annual Conference & Exposition*, Indianapolis, IN, 2014.
18. Virginia Department of Environmental Quality (VDEQ), *305(b)/303(d) Water Quality Assessment Integrated Report*, Richmond, VA, 2012.
19. Virginia Department of Environmental Quality (VDEQ), *Upper Stroubles Creek Watershed TMDL Implementation Plan Montgomery County, Virginia*, VT-BSE Document No. 2005-0013, Blacksburg, VA, 2006.
20. V. A. Levesque and K. A. Oberg, *Computing Discharge Using the Index Velocity Method. Techniques and Methods 3-A23,* U.S. Department of the Interior, U.S. Geological Survey, Reston, VA, 2012.
21. M. Rogers, *The Determination of Stream Discharge at the LEWAS Site on the Virginia Tech Campus,* M.S. Thesis, Virginia Polytechnic and State University, 2012.
22. J. L. Faust and D. R. Paulson, Active learning in the college classroom, *Journal on Excellence in College Teaching*, **9**(2), 1998, pp. 3–24.
23. M. Prince, Does active learning work? A review of the research, *Journal of Engineering Education*, **93**(3), 2004, pp. 223–231.
24. P. Dillenbourg, What do you mean by collaborative learning?, in P. Dillenbourg (Ed) *Collaborative-learning: Cognitive and computational approaches*, Oxford: Elsevier, 1999, pp. 1–19.
25. J. Cooper and R. Mueck, Student involvement in learning: Cooperative learning and college instruction, *Journal on Excellence in College Teaching*, **1**(1), 1990, pp. 68–76.
26. D. W. Johnson, R. T. Johnson and K. A. Smith, Cooperative learning returns to college what evidence is there that it works?, *Change: The Magazine of Higher Learning*, **30**(4), 1998, pp 26–35.
27. D. W. Johnson and R. T. Johnson, An educational psychology success story: Social interdependence theory and cooperative learning, *Educational Researcher*, **38**(5), 2009, pp. 365–379.
28. A. M. O'Donnell and A. King, *Cognitive Perspectives on Peer Learning*, Routledge Publications, New York, NY, 2014.
29. B. S. Bloom, *Taxonomy of educational objectives: The classification of educational goals: Handbook I—cognitive domain*, Longmans, Green and Co., New York, NY, 1956.
30. L. W. Anderson, D. R. Krathwohl, P. W. Airasian, K. A. Cruikshank, R. E. Mayer, P. R. Pintrich, J. Raths and M. C. Wittrock, *A taxonomy for learning and teaching and assessing: A revision of Bloom's taxonomy of educational objectives*, Addison Wesley Longman, 2001.
31. G. L. Downey, Are engineers losing control of technology? From "problem solving" to "problem definition and solution" in engineering education, *Chemical Engineering Research and Design*, **83**(8), 2005, pp. 1–12.
32. J. A. Cantor, *Experiential Learning in Higher Education: Linking Classroom and Community*, ERIC Clearinghouse on Higher Education, Washington, D.C., 1997.
33. J. G. Greeno, A. M. Collins and L. B. Resnick, 1996. Cognition and learning, in D. C. Berliner and R. C. Calfee (eds), *Handbook of educational psychology*, Macmillan Library, New York, NY, 1996, pp. 15–46.
34. J. G. Greeno, The situativity of knowing, learning, and research*, American Psychologist*, **53**(1), 1998, pp.5–26.
35. J. Lave and E. Wegner, *Situated Learning: Legitimate Peripheral Participation*, Cambridge University Press, New York, NY, 1991.
36. S. Scribner, Studying working intelligence, in E. Tobach, R. J. Falmagne, M. B. Parlee, L. M. W. Martin and A. S. Kapelman (eds), *Mind and social practice: Selected writings of Sylvia Scribner*, Cambridge University Press, New York, NY, 1997, pp. 308–318.

37. A. Johri, B. M. Olds and K. O'Connor, Situative frameworks for engineering learning research, in A. Johri and B.M. Olds (eds), *Cambridge handbook of engineering education research*, Cambridge University Press, New York, NY, 2014, pp. 47–66.
38. J. V. Wertsch, *Voices of the Mind*, Oxford University Press, New York, NY, 1998.
39. R. A. Engle, Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom, *Journal of the Learning Sciences*, **15**(4), 2006, pp. 451–498.
40. W. C. Newstetter and M. D. Svinicki, Learning theories for engineering education practice, in A. Johri and B. M. Olds (eds), *Cambridge handbook of engineering education research*, Cambridge University Press, New York, NY, 2014, pp. 29–46.
41. H. B. Glasgow, J. M. Burkholder, R. E. Reed, A. J. Lewitus and J. E. Kleinman, Real-time remote monitoring of water quality: A review of current applications, and advancements in sensor, telemetry, and computing technologies, *Journal of Experimental Marine Biology and Ecology*, **300**(1–2), 2004, pp. 409–448.
42. J. Ma and J. V. Nickerson, Hands-on, simulated, and remote laboratories: A comparative literature review, *ACM Computing Surveys*, **38**(3), 2006, pp. 1–24.
43. B. Balamuralithara and P. C. Woods, Virtual laboratories in engineering education: The simulation lab and remote lab, *Computer Applications in Engineering Education*, **17**(1), 2009, pp. 108–118.
44. L. Gomes and J. García-zubía, *Advances on remote laboratories and e-learning experiences*, **6**, Duesto Publications, Bilbao, Spain, 2007.
45. International Data Corporation, *Worldwide New Media Market Model*, http://www.idc.com/getdoc.jsp?containerId=249178. Accessed 14 August 2014.
46. C. Crawford, *Art of Interactive Design: A Euphonius and Illuminating Guide to Building Successful Software*, No Starch Press, San Francisco, CA, 2002.
47. S. Alessi and S. Trollip, *Multimedia for Learning: Methods and Development*, 3rd edn, Allyn & Bacon, New York, NY, 2000.
48. J. McGourty, C. Sebastian and W. Swart, Developing a comprehensive assessment program for engineering education, *Journal of Engineering Education*, **87**(4), 1998, pp. 355–361.
49. M. Bailey, R. B. Floersheim and S. J. Ressler, Course assessment plan: A tool for integrated curriculum management, *Journal of Engineering Education*, **91**(4), 2002, pp. 425–434.
50. J. A. Shaeiwitz, Classroom assessment, *Journal of Engineering Education*, **87**(2), 1998, pp. 179–183.
51. A. Onwuegbuzie and C. Teddlie, A framework for analyzing data in mixed methods research, in A. Tashakkori and C. Teddlie (eds), *Handbook of mixed methods in social & behavioral research*, Sage Publications, Thousand Oaks, CA, 2003.
52. B. Moskal, Using assessment results for improving student learning, in J. Spurlin, S. Rajala and J. Lavelle (eds), *Designing better engineering education through assessment: A practical resource for faculty and department chairs on using assessment and ABET criteria to improve student learning*, Stylus Publishing, Sterling, VA, 2008, pp. 117–148.
53. N. K. Denzin, *The research act: A theoretical introduction to sociological methods*, McGraw-Hill, New York, NY, 1978.
54. D. L. Driscoll, A. Appiah-Yeboah, P. Salib and D. J. Rupert, Merging qualitative and quantitative data in mixed methods research: How to and why not, *Ecological and Environmental Anthropology*, **3**(1), 2007, pp. 19–28.
55. M. B. Miles and A. M. Huberman, *Qualitative Data Analysis*, 2nd edn, Sage Publications, Thousand Oaks, CA, 1994.
56. A. Tashakkori and C. Teddlie, *Mixed Methodology: Combining Qualitative and Quantitative Approaches*, vol. 46, Sage Publications, Thousand Oaks, CA, 1998.
57. M. Sandelowski, Focus on research methods combining qualitative and quantitative sampling, data collection, and analysis techniques in mixed-method studies. *Res. Nurs. Health*, **23**(1), 2000, pp. 246–255.
58. B. M. Moskal, J. A. Leydens and M. J. Pavelich, Validity, reliability and the assessment of engineering education, *Journal of Engineering Education*, **91**(3), 2002, pp. 351–354.
59. J. L. Fleiss, B. Levin and M. C. Paik, The measurement of interrater agreement, in *Statistical methods for rates and proportions*, 2nd edn, 1981, pp. 212–236.
60. Accreditation Board of Engineering Technology (ABET), *2013–2014 Criteria for Accrediting Engineering Programs*. http://www.abet.org/uploadedFiles/Accreditation/Accreditation_Step_by_Step/Accreditation_Documents/Current/2013_-_2014/eac-criteria-2013-2014.pdf. Accessed 14 August 2014.
61. R. A. Singleton and B. C. Straits, *Approaches to social research*, Oxford University Press, New York, NY, 2010.
62. Virginia Tech Fall 2012 Hydrology Class Blog, https://blogs.lt.vt.edu/cee4304f2012/. Accessed 15 September 2012.
63. Virginia Tech Spring 2014 Hydrology Class Blog, http://cee4304spring2014.blogspot.com/. Accessed 15 December 2013.
64. D. S. Brogan, W. M. McDonald, V. K. Lohani, R. L. Dymond and A. J. Bradner, A high-frequency real-time system for creating and sharing environmental data, *Advances in Engineering Education (AEE)*, 2013, Under review.
65. Introduction to Engineering Blog, Virginia Western Community College, Spring 2013, http://vwcclewas.blogspot.com. Accessed 14 August 2014.
66. Introduction to Engineering Blog, Virginia Western Community College, Fall 2013, http://lewasfall2013.blogspot.com. Accessed 14 August 2014.
67. Introduction to Engineering and Engineering Methods Blog, Virginia Western Community College, Fall 2013, http://egr124fall2013.blogspot.com. Accessed 14 August 2014.

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