Combined Contribution of 12 REU Students to the Development of the LEWAS Lab

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water sciences and engineering at VT since 2007. This site has 66 alumni to date. Dr. Lohani collaborated with his colleagues to implement a study abroad project (2007-12), funded under the US-Brazil Higher Education Program of the U.S. Department of Education, at VT. He has published over 70 papers in peer-reviewed journals and conferences.

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Abstract

The Learning Enhanced Watershed Assessment System (LEWAS) lab is a high-frequency, real-time environmental monitoring lab located on the campus of Virginia Tech. This lab has developed over the course of 9 years from a prototype system used in one class to a real-time environmental monitoring system that has been in used in 21courses across 6 institutions and in 3 countries. Throughout its development, this lab has also hosted an NSF/REU site at Virginia Tech for 8 years. Every year for 10 weeks during the summer 8-11 students, coming from several universities and having various disciplinary backgrounds, join the site. Among them, 1-2 engage in interdisciplinary research work in the LEWAS lab, while others join different research labs across the Virginia Tech campus. As of 2015, 12 REU fellows have been mentored by the faculty advisors and the graduate students (including four authors of this paper) of this lab. In this paper, we will discuss the work of these 12 REU fellows and how their combined contribution aided the development of the present LEWAS lab. In 2007, the first REU student to join the lab developed a simple prototype for a wireless data collection system, aiming to design an on-campus watershed sciences and engineering laboratory. This prototype iteratively evolved with the help of other REU students to the present LEWAS, which has the following four stages: 1) data inputs that consist of environmental instruments including an acoustic Doppler current profiler, a water quality sonde and a weather station each taking measurements every 1-3 min., 2) data processing occurring locally on a Raspberry Pi, 3) data storage on a remote server and 4) data visualization through an Online Watershed Learning System (OWLS) (www.lewas.centers.vt.edu/dataviewer) through which end users access the LEWAS data for research and education. Each REU fellow significantly contributed to the development/maintenance/application of two or more of these stages. The implementation of all four stages was a complex process that required interdisciplinary knowledge and skills, which were obtained not only through graduate mentors representing different disciplines (engineering education, civil & environmental engineering, electrical & computer engineering, computer science and environmental science) but also REU students who were pursuing a range of undergraduate degrees (civil & environmental engineering, computer science, computer engineering, chemical engineering and environmental science). Through research experiences in an interdisciplinary lab, REU fellows were exposed to a wide spectrum of learning and research work, beyond their disciplinary domain. The authors, in turn gained experience mentoring the REU fellows in their research work. The knowledge shared in this paper demonstrates how an interdisciplinary engineering system/lab can be iteratively built as a result of undergraduate research work under graduate mentorship. This study also shows how an REU program can support the development of an engineering lab as well as the research of several masters and PhD students.

Keywords: Research Experience for Undergraduates (REU), mentoring, interdisciplinary, environmental monitoring.

Introduction

The LEWAS lab is a unique real-time high-frequency environmental monitoring lab established to promote environmental monitoring education and research[1- 5]. This system was conceived as a part of a PhD dissertation in the Engineering Education Department at Virginia Tech[1]. It has developed over the course of 9 years (2007 to 2016) from a prototype system used in one class to a real-time environmental monitoring system that has been in used in 21 courses across 6 institutions in 3 countries. Throughout its development, this lab has also hosted an NSF/REU site at Virginia Tech for 8 years[6,7].

This NSF-REU site was established in 2007. It has successfully completed two cycles of implementation (2007-09; 2011-13)[6]. Currently, the third cycle is in progress and will be completed at the end of summer 2016. As of the summer of 2015, the site has graduated 76 excellent undergraduate researchers (REU fellows; 47 women & 29 men) representing 55+ different institutions located across the United States and Canada. Every year for 10 weeks during the summer 8-11 students, having various disciplinary backgrounds, join the site. Faculty members and their graduate students from a variety of disciplines including civil and environmental engineering, engineering education, geosciences, biological sciences, industrial design, biological systems engineering, forest resources & environmental conservation, and crop and soil environmental sciences mentor undergraduate researchers to conduct research on various interdisciplinary aspects of water sciences and engineering. The REU fellows receive opportunities to conduct independent research and improve their communication (written and verbal) skills. Field trips and weekly seminars for the fellows are organized in order to develop their professional skills. Weekly social interactions are facilitated to enhance personal and professional bonding among fellows and with faculty/graduate students.

Among all these REU fellows, each year 1-2 engage in interdisciplinary research work in the LEWAS lab [6]. As of 2015, 12 REU fellows have been mentored by the faculty advisors (including the fifth author) and the graduate students (including the four other authors of this paper) of this lab. Through the research experience gained in the interdisciplinary LEWAS lab, the REU fellows were exposed to a wide spectrum of learning and research work beyond their disciplinary domain. In this paper, we will discuss the three following primary areas: 1) the work of these 12 REU fellows that contributed to the development of the present LEWAS lab, 2) the interdisciplinary experience gained by these undergraduates by working in the LEWAS lab, and 3) the lessons learned from the authors though their experiences assisting the REU fellows in their research work.

Background of the LEWAS lab

The LEWAS lab has a field site (Figure 1), which is located at the outlet of a small creek (Webb Branch) that flows through the Virginia Tech campus[8]. This stream joins a water quality impaired stream Stroubles Creek[9]. The Webb Branch was chosen as the site of the lab because of its environmental significance as also due to its proximity to the campus[10]. The LEWAS field site drains a watershed which is approximately 2.78 km^2, and approximately 95% urban[11]. The LEWAS field site draws power from both the grid and a pair of photovoltaic panels and connects to the campus wireless network through a high-gain antenna in order to transmit measured data from instruments.

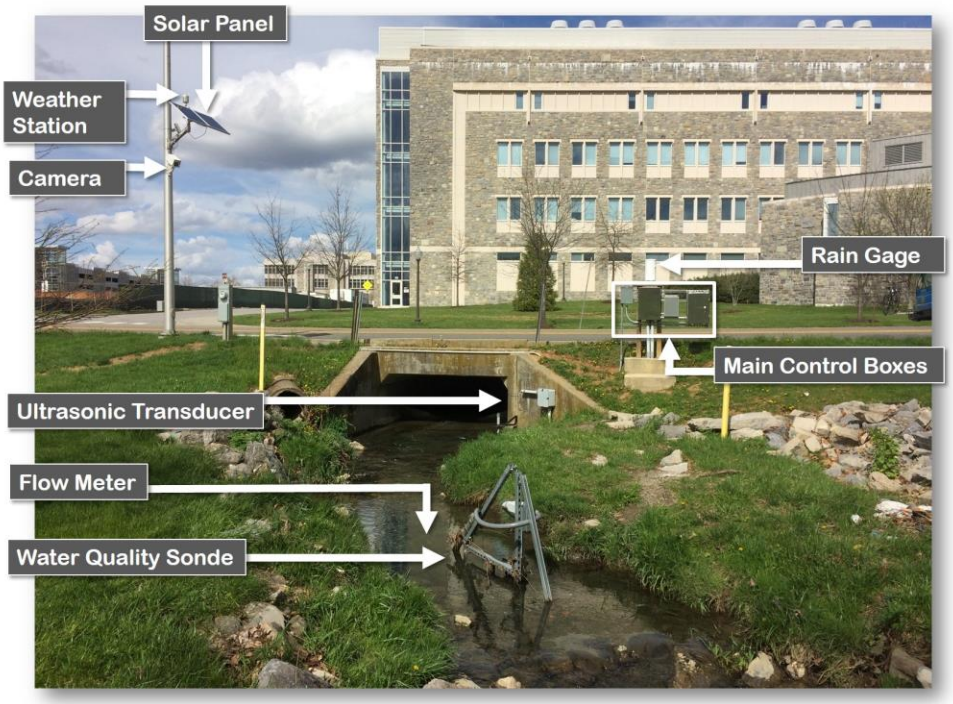

Figure 1. The LEWAS lab field site.

At present, the LEWAS has the following four stages[12,13] (Figure 2): 1) Instruments that are used for environmental monitoring including an acoustic Doppler current profiler, a water quality sonde and a weather station taking measurements every 1-3 min., 2) data processing occurring locally on a Raspberry Pi, 3) data storage on a remote server and 4) end user interfaces (local and remote), which enable users to visualize LEWAS data, e.g., the Online Watershed Learning System (OWLS) (www.lewas.centers.vt.edu/dataviewer) for research and education. The LEWAS has been designed as a flexible and expandable environmental monitoring system that can easily be adapted and deployed in a wide variety of settings.

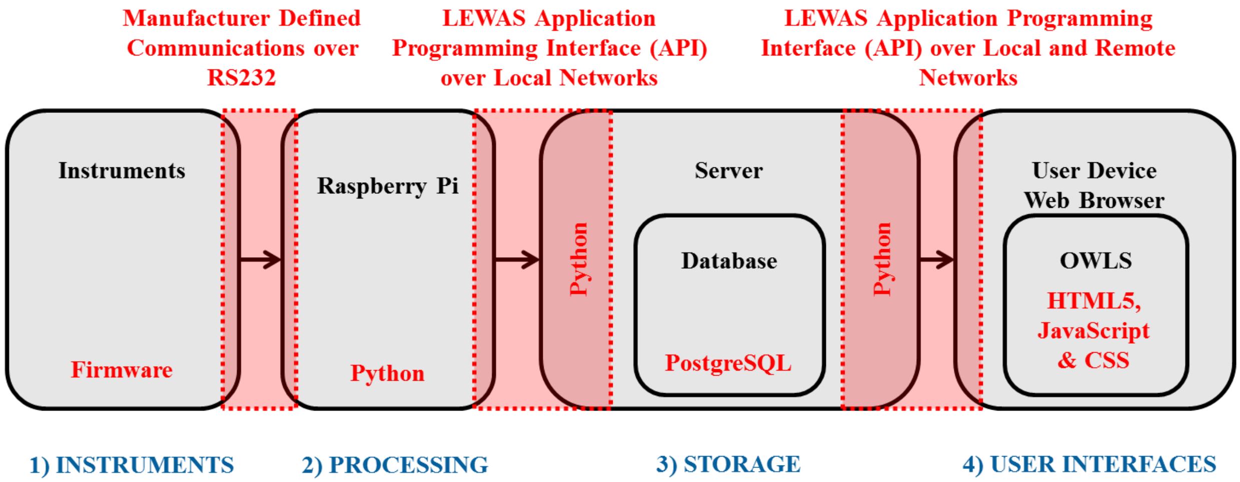

Figure 2. Data flow from instruments to user interfaces of LEWAS

Diverse expertise and skill sets are required to design, implement and maintain the various stages of the LEWAS. In order to meet these requirements, the LEWAS lab has an interdisciplinary team consisting of two faculty members and several graduate and undergraduate students from various academic backgrounds including engineering education, electrical engineering, computer engineering, computer science, civil and environmental engineering, mechanical engineering and biology. This team meets on a weekly basis and is responsible for the continued development and expansion of the LEWAS lab and maintenance of its outdoor field site and indoor lab space.

Contributions of the 12 REU fellows

In 2007, the director of the LEWAS lab aimed to design an on-campus water science and engineering lab at Virginia Tech[2, 14, 15], which has now become a high-frequency, real-time environmental monitoring lab. The evolution and expansion of the lab to the present four stages (Figure 2) was a gradual iterative process assisted by the contributions of several graduate and undergraduate students including the REU fellows. Concurrent to the development, LEWAS lab is engaged in outreach activities designed to help the community learn about their watershed and environment. Dissemination of work is also a priority in the LEWAS lab, so that the knowledge gained by the researches in the lab can be shared with professionals both inside and outside the field. The REU fellows have contributed in these areas as well.

In Figure 3, we portray the areas of contribution of each of the 12 REU fellows (represented by dotted lines for the year that each one worked in the lab) either from the four different stages of the LEWAS or from the outreach and dissemination activities of the LEWAS lab, which are denoted by dots. The contribution of these REU fellows aided in the advancement of the lab through the following developmental phases: 1) Pre-Installation Development; 2) LabVIEW on a cRIO and 3) Python on a Raspberry Pi. These developmental phases are named according to the data acquisition system used at the particular time for collecting data from the instruments for data visualization, research and education.

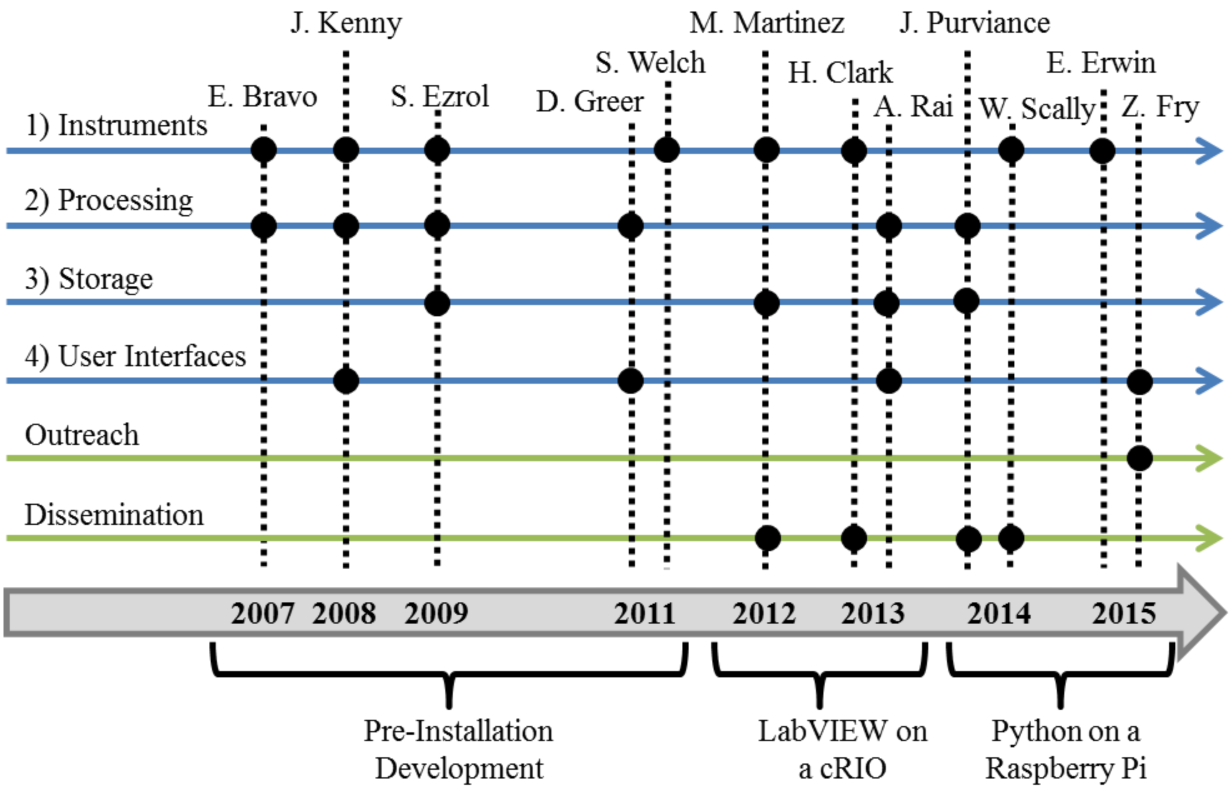

Figure 3. Contribution of 12 REU fellows to the development of the LEWAS lab

1) Pre-Installation Development

From 2007 until 2011, the LEWAS lab was at its initial stage when it transitioned from experimenting with simple sensors to using three main instruments: an acoustic Doppler current profiler, a water quality sonde and a weather station. In 2007, the field site was proposed but not selected. At that time, E. Bravo, who was a REU fellow, assisted in developing a prototype for a wireless data collection system[16]. He selected two simple water quality sensors, and established serial connection with a microcontroller between each sensor and windows laptop used to view the data from the sensors. In 2008, LabVIEW, a programming environment developed by National Instruments, was selected to be used for data acquisition. During that summer, the initial detailed design, layout and implementation plan for the LEWAS field site was established. J. Kenny, the REU fellow in 2008, contributed in the integration of a LabVIEW program on a windows laptop for reading water quality data from a multi-probe sonde and for visualizing it on a remote computer, connected via a Wireless LAN[17]. In 2009, S. Ezrol helped in the configuration of a compact embedded computer, called a cRIO, to handle on-site processing of real-time data from the sonde. He, along with his mentors, modified the previous LabVIEW code for the cRIO, which read data from the sonde, processed the data and stored it on an SD card for future retrieval. The functionality of the cRIO was tested in the indoor lab space. This was the first time an attempt was made to store data for future use. Construction of outdoor lab began in Fall 2009. However, the instruments and computers remained in the lab. Subsequently, lab members developed separate LabVIEW codes on a laptop running MS Windows in order to process data from each of the other instruments. In 2011 two REU fellows, D. Greer and S. Welch, worked in the lab. D. Greer explored and assisted in fixing the bugs of the existing LabVIEW programs and contributed to the development of the integrated LabVIEW program, which was capable of handling all the instruments, on a windows laptop[18]. In addition to the software development, proper operation of the measurement instruments is essential for successful lab operation. S. Welch explored and documented the importance of maintenance and calibration of the sonde and flow meter, which are integral to the LEWAS lab for collecting water quality and quantity data[19]. During this time, the instruments were not yet installed in the field site. S. Welch was a student from Virginia Tech who continued in her role in the lab during the following academic year during initial field deployment of the instruments.

2) LabVIEW on a cRIO

During the winter of 2011-12, the LEWAS lab progressed in its development as the field site was set up with the installation of the instruments, the cRIO, a power system and the wireless antenna. The cRIO ran a unified LabVIEW program in FPGA (Field Programmable Gate Array) format at the field site. During that time, the cRIO was used as a data acquisition system for one instrument at a time. M. Martinez, who joined the lab during the summer of 2012, contributed in the modification of the weather station program to collect data as well as store data in a SD card[20]. During the summer of 2013, two REU fellows joined the lab. A. Rai designed a mysql database, from which data was accessed by users through an interactive web-interface[21]. Although the original plan for the summer was to complete the first implementation of data flow from the sensor to the remote user via a database, A. Rai's research proved that, although it is a very capable system, the cRIO was not well suited for the LEWAS lab due to its power consumption and limited number of inputs. During the same period, in addition to working on the calibration of the instruments, H. Clark constructed an accurate storm-water network map that aids in the understanding of the LEWAS lab watershed[22].

3) Python on a Raspberry Pi

By the end of 2013 it was determined that a Raspberry pi, a simple and inexpensive credit card sized computer, was a better choice to collect data from multiple instruments simultaneously in the field site than the cRIO was. The Raspberry Pi also consumed less power than the cRIO did and had flexibility in being compatible with several programming languages[12]. At this time, the lab also transitioned from using LabVIEW to python as the language for processing the data, since python is an open source language. In the summer of 2014, REU fellow J. Purviance was able to develop code in python to acquire data from the three main instruments and store it in a local database on the Raspberry Pi[12]. This system was further improved by lab members into the current four stages. Now using the stable system the users are able to access the data of LEWAS lab for research and education[13].

W. Scally, also an REU fellow in 2014, assessed the effectiveness of various methods for estimating flow using index-velocity techniques in an urban stormwater network[23]. In 2015, E. Erwin continued investigation into the watershed characteristics[24]. With the data acquisition system in place providing real-time data to a web-based interface, Z. Fry, an REU fellow of 2015, was able to investigate how members of the community might use the data collected by the LEWAS lab[25]. He designed a survey that was distributed to water management professionals at Virginia Tech and the local town to collect information about how they might want to use real-time data. This data is currently being analyzed. In addition, Z. Fry developed a prototype user interface that would allow community members to submit geotagged images taken around the watershed to assist in diagnosing water quality problems detected at the LEWAS lab field site. Overall, the contributions made by these 12 REU fellows have been integral to the ongoing development of the LEWAS lab.

Interdisciplinary experience of the REU fellows

Interdisciplinary experience helps people to understand and utilize knowledge and modes of inquiry drawn from outside their own disciplines[26]. Interdisciplinary experience helps students to develop appreciation for other disciplines, enabling them to integrate and analyze various disciplinary perspectives by critically thinking through them, and ultimately envisioning innovative solutions to a problem. This also assists students to develop critical thinking skills and to understand the limitations and weaknesses of their own disciplines[26,27].

LEWAS lab with its interdisciplinary team and research work, helps graduate and undergraduate students (including REU fellows), who engage in research projects in the lab, to gain interdisciplinary experience. Table 1 shows the background discipline of the REU fellows, the project they were engaged in and other disciplinary knowledge that they were exposed to. For example, M. Martinez, who was from Biological Systems Engineering with a background in chemistry, gained experience of programming as well as civil and environmental engineering. In his research report he mentioned

> *"During the 10-week summer project, the lead author had the opportunity to work in an interdisciplinary team to study a real-time environmental monitoring system. This taught him how to work with students from different majors to solve environmental related problems. It gave him skills to solve problems that are not directly related to his chemical engineering background. Examples of some scientific concepts that he learned during the study are: Relationship between land use and water quality; Relationship between water quality and ecology; Basics of LabVIEW programming and data acquisition; Integration of software and hardware components of a real-time environmental monitoring system* "[20].

Similarly, Z. Fry, with a background in civil engineering, developed his web development and programming skills in the implementation of a web-based interface. He also gained experience in survey instrument design to collect data from stakeholders. Thus we see, REU fellows joining the LEWAS lab went beyond their disciplinary knowledge and skills to work in their research projects. This helped them to gain interdisciplinary experience**.** In addition to the specific focus areas shown in Table 1, every REU fellow obtained a basic understanding of the four stages of the LEWAS lab.

REU Fellow	**Project Name**	**Background Discipline**	**Other Disciplinary Experience**
E. Bravo	Developed a prototype for wireless	Electrical Eng.	Hydrologic and water

	data collection system		quality sensors
J. Kenny	Integrated LabVIEW into Stroubles creek watershed assessment	Civil and Environmental Eng.	LabVIEW programming
S. Ezrol	Configured a cRIO device for the real-time water quality measurement of Stroubles creek	Computer Science	Water quality sensors
D. Greer	Developed LabVIEW virtual instrument for implementation in environmental monitoring in real time	Industrial Eng.	LabVIEW programming
S. Welch	Explored calibration and maintenance procedure of real time water quality monitoring devices	Industrial Eng.	Sensor calibration
M. Martinez	Studied the application of a real-time environmental monitoring system	Biological Systems Engineering	LabVIEW programming
H. Clark	Investigated the response of the Stroubles creek watershed to acute toxicity events via real-time data analysis	Environmental Sciences	Environmental Engineering; Biological Engineering
A. Rai	Designed a LabVIEW enabled real-time weather monitoring system with an interactive database	Electrical and Computer Eng.	Sensor calibration
J. Purviance	Worked on developing a high frequency environmental monitoring using a Raspberry Pi-based system	Computer Science	Water quality, quantity and weather sensors
W. Scally	Compared the flow computation methods in an urban storm water network	Civil and Environmental Eng.	Data Analytics
E. Erwin	Investigated the efficacy of using turbidity measurements as a proxy for nutrient levels	Geology	Environmental Engineering; Biological Engineering
Z. Fry	Community survey and geotagged photo acquisition user interface	Civil Engineering	Web design, survey instrument design

Table 1. Interdisciplinary experience gained by the 12 REU fellows from the LEWAS lab

Graduate student mentors' experiences and lessons learned

Mentors have the roles of providing guidance and encouragement to the mentees as well as sharing knowledge. Through the mentoring experience, each mentor develops effective methods to communicate and work with a mentee, which can help the mentor in their professional environment[28]. For example, being a mentor as a graduate student provides experience that can later help a faculty member to mentor his/her students. Additionally, research has pointed out that mentoring has a positive impact on a number of student outcomes including student performance, intellectual and critical thinking skills and student's self-confidence[29,30]. Therefore, mentoring experience is advantageous for both the mentor and the mentee.

The first four authors in this paper, who are also graduate students associated with LEWAS lab, each have one or more years of mentoring experience in the NSF/REU program on Interdisciplinary Water Science and Engineering. In each sub-section below, one of the first four authors discusses the ways that he/she had been associated with the program and one of the primary mentoring insights gained or lessons learned by that author while assisting the REU fellows in their research work. These insights and lessons help to highlight various aspects of mentoring experience that can be beneficial to future mentors associated with similar types of programs. The overall lessons learned as outlined in the following sections are the (1) necessity of setting timelines for project completion given the short timeline (10 week) to complete a research project, (2) need to adapt a project to a student's set of abilities and skills, (3) importance of creating synergistic research projects that align with the existing goals and efforts of the lab, and (4) difficulty of providing agency to the undergraduate REU student in developing their own project.

First author's experience: Planning and setting timelines for project completion

The first author has been engaged with the REU program for the last two years and also for the current year. With the program director (fifth author) she is primarily responsible for the administrative work of the site, such as setting up the application process, organizing the orientation ceremony, etc. She is also engaged in modifying the assessment plan of the REU site in collaboration with an assessment expert to improve evaluation of the program. She personally mentored one REU fellow in 2014 and will be mentoring another fellow in the summer of 2016. The project of the mentee of 2014 was related to the development of the processing and storage stage of the LEWAS lab using python programming on a Raspberry Pi. The work has resulted into one conference publication[12].

According to her experience, at the beginning of the 10 week project, REU fellows first need to understand their project, acclimate to the program/lab ambiance and then start from there. Along with engaging in research work, REU fellows are committed to spend time for professional activities, such as attending seminars, field trips, giving presentations, etc. Thus, REU fellows need to plan their work at the very beginning, so that they can accomplish their goal of completing their research projects and writing their research papers for the REU proceeding within these ten weeks. It is very critical for a graduate mentor, to guide mentees in setting sub-goals and in planning timelines for their projects. As a more experienced researcher, mentors can anticipating the challenges that might arise while conducting the research. Sharing these experiences with the REU fellows, can help them in making effective plans of their projects. Setting sub-goals and timelines, also helps mentors to guide mentees and to keep track of their progress. REU fellows, by planning their project and by following their timelines, learn to organize and systematize their work. This lifelong learning can assist them in future research projects.

Second author's experience: Interdisciplinary experience

The second author has been a graduate student mentor for three summers and has personally mentored three students over the span of that time. The work over these three summers has focused on surface water quality and stormflow measurement methods and techniques. This work has also resulted in 1 conference[30] publications and 1 journal publication[3] with an undergraduate REU student as a lead or contributing author.

According to his experience, one of the unique challenges about an REU program is that many times the students that come to conduct summer research are high performing students, however, they have a different disciplinary background. For instance, two of the REU students that came into the laboratory to conduct civil and environmental engineering projects were from environmental science programs. This resulted in a need to tailor the student research projects to the strength of that student, while still challenging them to learn about contemporary issues, methods, and theories outside of their discipline. For example, one student was from an environmental science program and had previously conducted field work collecting Total Suspended Solids (TSS) streamflow samples as an undergraduate researcher. This student went on to develop a TSS to Turbidity relationship at the site through grab sampling of TSS and continuous monitoring of Turbidity. This allowed the student to use their strength and previous experience in field work and apply it to an environmental engineering problem in an urban watershed. Without recognizing where the students are coming from and what background and skillsets they possess, it can be difficult in developing a 10-week project that the student can take on and complete successfully.

Third author's experience: Selecting potential research projects

The third author has been a member of the LEWAS lab team for more than four years and mentored a total of 2 REU fellows over his first 2 summers in the lab. He has been involved in conversations concerning selection of project topics for 8 REU fellows in LEWAS lab from 2012 through 2016. As the second and fourth authors point out in this section, successful REU projects are aligned with REU fellows' background and interests. However, it is also desirable that these projects align with lab goals. Based on the third author's experience, he believes that project topics can fit into two primary categories, i.e. continuation of prior work and expansion into new areas. For example, J. Purviance continued the work of A. Rai using a different hardware and software environment. This research was a key step in the continued development of the lab. On the other hand, Z. Fry expanded the work of the lab by adding a new outreach approach and by developing a new type of user interface. As pointed out by the fourth author below, having a several possible projects prepared in advance is important, and potential projects can be selected from these two primary categories. As a researcher, it is important to understand that not every REU project will contribute to the existing research goals. However, continued development projects can lead to key contributions in a larger existing research project. On the other hand, expansion projects are exploratory in nature and may or may not grow into more significant research areas. Ultimately, it is important to bear in mind that the goal of the REU program is to benefit the REU fellows, and that benefit to the researcher's own projects is of secondary importance.

Fourth author's experience: Giving agency to students to select their project

The fourth author's first mentoring experience was in the summer of 2015. As an overarching goal for the experience he wanted to give as much agency as possible to his student. He planned to co-construct a research project with his REU fellow to help ensure it was a project both mentor and mentee were interested in. The REU fellow's interest in user interface design and data visualization led to a plan to develop an interface that would allow community members to take photographs around the watershed that would aid in diagnosing potential water quality problems detected at the LEWAS lab field site.

While both the fourth author and his REU fellow were ultimately satisfied with the project selected and the work accomplished. According to this experience, a significant challenge was allowing enough time for co-creating a project plan with enough time left in the summer to put the plan into action. Without a project already planned out and ready to go with the REU fellow arrived, the first 2-3 weeks of the program were consumed with project brainstorming and planning. Once it was determined that a community survey would be needed it took additional time to develop and distribute the survey. As a result no survey results were returned in time for the REU fellow to analyze. While the fourth author still feels strongly about the importance of co-designing a project with the REU fellow, if he were to do it again he would try to have several rough project ideas developed before the program that could potentially be modified to meet the REU fellow's interests. Additionally, if possible, communicating regularly with the REU fellow before the start of the program may help design a project specific to the student's interests before the student arrives on site.

Conclusion and future work

In this paper we discussed the way the 12 REU fellows contributed to the development of LEWAS lab, where these fellows conducted research during the NSF/REU program. This shows how undergraduate researchers under the guidance of graduate mentors can contribute to the iterative development of an interdisciplinary system/lab. By working in this lab environment, the REU fellows received the opportunity to gain interdisciplinary experience, which broadened their perspective and aided them in understanding the importance of other disciplines. Additionally, the graduate mentors obtained valuable insights into several practical aspects mentoring students, and they believe that the lessons they learned will be useful for future mentors.

During the 2016 REU program the members of LEWAS lab will engage an REU fellow. The REU fellow will learn to calibrate the sensors of LEWAS lab, and will help in developing case studies to demonstrate the use of high frequency data in environmental monitoring. Members of the LEWAS lab have been engaged in development of these case studies to assist students and to help community members understand the impact of real life events on the water data. The REU fellow will also engage in programming new features for the OWLS user interface using python, HTML5, CSS and JavaScript, which will help users engaged in environmental monitoring to access environmental data and perform analysis. This programming will include tracking these users and finding their navigational paths through the user interface. These REU projects are intended to extend the current system of the lab.

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