Benefits for Undergraduates from Engagement in an Interdisciplinary Environmental Monitoring Research and Education Lab

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Daniel S. Brogan a postdoctoral associate working on engaged learning at the Institute for Critical Technology and Applied Science at Virginia Tech. From 2011 to 2017 he was a doctoral student in engineering education at Virginia Tech, where his research involved the development and classroom implementation of the Online Watershed Learning System (OWLS), a guided, open-ended cyberlearning environment that is driven by HTML5, JavaScript and CSS (http://www.lewas.centers.vt.edu/dataviewer/) and serves as a user interface to the Learning Enhanced Watershed Assessment System (LEWAS) Lab. In 2011 he founded Bhutanese-Nepali Christian Media Ministries, which utilizes online media to address needs in Christian ministries for people in these language groups. Prior to June 2010, he was a graduate student at the University of New Hampshire, where he earned his BS and MS degrees in electrical engineering.

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Nicholas Falls was born in Roanoke, Virginia on June 30, 1995. After graduating from James River High School, he attended Virginia Western Community College where he received an Associate's degree in Engineering in 2015. Upon graduation from community college, he transferred to Virginia Polytechnic Institute and State University where he studied Electrical Engineering with plans to graduate in the spring of 2018. Over the summers he worked as an intern at Gala Industries where he worked along side electricians reading and troubleshooting schematics and wiring the equipment. He was also involved in an the LEWAS lab, an undergraduate research lab at Virginia Tech where he investigated solar power and using it to power equipment. He graduated from Virginia Western with the honor of Suma Cum Laude. At Virginia Tech he was involved in many clubs and organizations including the Student Government Association, Eta Kappa Nu (the Electrical and Computer Engineering honor society), the LEWAS lab, Phi Sigma Kappa (a social fraternity), and the Electrical and Computer Engineering ambassadors.

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Abstract

An interdisciplinary approach to research is essential to solving the complex global problems of the 21st century. In order to tackle these multifaceted problems, undergraduates need to gain interdisciplinary experiences beyond the knowledge and skills of their disciplinary silos. Interdisciplinary experiences help students to develop appreciation for other disciplines, enabling them to integrate and analyze various disciplinary perspectives by critically thinking through them, and ultimately helping them to envision innovative solutions to complex problems. These experiences also assist students in understanding the limitations and weaknesses of their own disciplines. Undergraduate experiential interdisciplinary learning experiences are a priority defined by the president of Virginia Tech as it relates to the broader visionary goals of the University. Within this context, the Learning Enhanced Watershed Assessment System (LEWAS) is a high-frequency, real-time environmental monitoring lab located on the campus of Virginia Tech. Since the lab started in 2008 it has been utilized in 26 undergraduate courses at 8 community colleges and universities across 3 continents, via its experiential learning initiatives. It has an interdisciplinary team that consists of two faculty members, one post doc, five graduate students and six undergraduate students from various academic backgrounds including engineering education, electrical engineering, mechanical engineering, computer science, civil and environmental engineering, chemical engineering, biological systems engineering, crop & soil environmental science, and biology. The benefits for undergraduates engaged in this interdisciplinary research lab are the focus of this paper. These are based on the personal experiences of five undergraduates, from five engineering majors, who are engaged in this lab. Each one of these five undergraduates has had either a graduate or a postdoc mentor and a faculty advisor. They have been engaged with the lab for various lengths of time from 2 semesters to 5 years, and each one typically works there for 5-10 hours per week. Further details about these undergraduates will be elaborated on in the paper. Being involved with various interdisciplinary real-world research projects with team members from multiple disciplines has helped these undergraduates to gain experiences outside their own disciplines. This has aided them in developing diverse skill sets that are described in terms of: interdisciplinary experiences, links between their classroom learning and lab experiences, academic and professional skills, impacts of faculty and graduate mentoring, and impacts on academic and career decisions.

1. Introduction

In order to tackle the multifaceted problems of the 21st century, industries often engage employees from multiple disciplines to solve a single problem. Although, industries have recognized the need for interdisciplinary collaborations, the departmental structures in colleges and universities have been significant barriers to students gaining interdisciplinary experience.[1] Within such settings, engaging in undergraduate research in an interdisciplinary research lab is a significant opportunity for undergraduates to gain interdisciplinary experience outside of their classrooms and departments. Engaging in interdisciplinary research is an experiential learning

initiative, where undergraduates can navigate through a real-life research problem and learn from their experience. [2] Moreover, undergraduate research experience has proven to benefit undergraduates by developing several academic and professional skills.[3] It also helps students to integrate and retain skills and to transfer them to professional settings.[4] Additionally, individual mentoring of undergraduates during these research experiences has been effective in increasing the undergraduates' retention in the STEM disciplines.[5-7]

Within this context, the Learning Enhanced Watershed Assessment System (LEWAS) lab is a high-frequency, real-time environmental monitoring lab located on the campus of Virginia Tech with the following three primary goals: 1) to engage in interdisciplinary research with cutting-edge technology for advancing the environmental monitoring research, 2) to bring this research into practice by educating engineers and non-engineers with hands-on authentic problems, and 3) to educate the community with the experiences gathered from research and practice. [8-10] The LEWAS lab has a field site, which is located at the outlet of a small urban creek (Webb Branch) that flows through the Virginia Tech campus. [11] The field site drains a watershed which is approximately 2.78 km^2 and approximately 95% urban land use. [12] At present, the LEWAS has the following four stages (Figure 1): 1) instruments in the field site that are used for environmental monitoring including an acoustic Doppler current profiler (ADCP), a water quality sonde and a weather station taking measurements every 1-3 min., 2) data processing occurring locally on a Raspberry Pi in a control box at the field site, 3) data storage on a remote server on the Virginia Tech campus and 4) end user interfaces (both local and remote), which enable users to visualize the historic and real-time LEWAS data using a system called Online Watershed Learning System (http://www.lewas.centers.vt.edu/dataviewer/) for research and education. [13,14,15] The LEWAS lab field site draws power from both the grid and a regulated pair of photovoltaic panels and connects to the campus wireless network through a high-gain antenna in order to transmit measured data from the instruments. 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.

In order to advance and maintain the LEWAS, people with diverse backgrounds and skill sets are required. [15] To meet this need, the LEWAS lab has an interdisciplinary team of faculty members and students. Currently the lab team consists of the following: a) a faculty member from engineering education department, who is also the director of education and global initiatives at Virginia Tech's premier research institute called the Institute of Critical Technologies and Applied Sciences (ICTAS) and a faculty member from civil and environmental engineering, b) one post doc having background in electrical engineering and engineering education, c) four doctoral and one master's degree students having backgrounds in computer science, mechanical engineering, chemical engineering, environmental engineering and engineering education, and d) six undergraduate students from computer science, civil and environmental engineering, electrical engineering, biological systems engineering, and crop and soil environmental sciences. For smooth functioning of the team, each undergraduate student is mentored by one or more graduate students and/or the post doc and by the faculty members. As discussed in the next section, undergraduates and graduates with various disciplinary strengths focus on various parts of the system. However, they also work collaboratively as an interdisciplinary team to continue attaining the goals of the LEWAS lab, to maintain the field site, to keep the system live, and to expand the scope of the lab. The entire interdisciplinary team meets once every two weeks to

discuss each member's progress, to address any concerns and to share knowledge. Additionally, sub-groups responsible for different lab activities, meet as per their requirements.

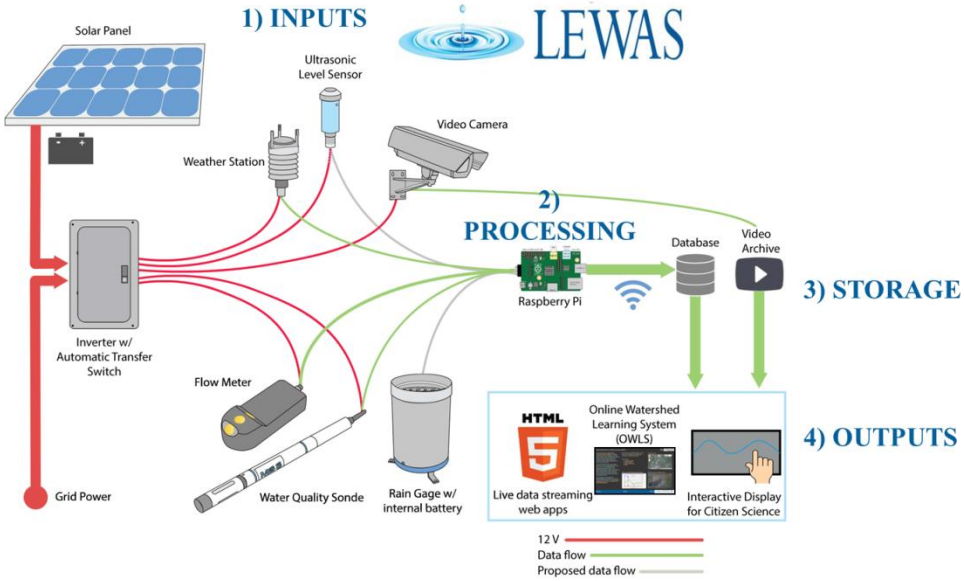

Figure 1. The system of the LEWAS lab

So far, three PhD students (two in engineering education and one in civil and environmental engineering) and six master's students (five in civil and environmental engineering and one in crop and soil environmental sciences) have graduated by conducting LEWAS lab-based research.[16-24] From the educational perspective, LEWAS including the OWLS has been utilized in 26 undergraduate courses at 8 community colleges and universities across 3 continents including 15 courses in 5 colleges in Virginia Tech.[11, 13, 14, 16-18, 25-31] For implementation in courses, numerous LEWAS lab-based learning activities have been developed including case-studies, projects, hands-on activities, week-long environmental monitoring activities, and problem solving assignments. The common objective behind all these activities is to aid students' learning and motivation using real-world problems based on real-time high frequency data. For outreach activities, members of the LEWAS lab actively participate in many events organized for community education, such as science fairs and science nights. There are also LEWAS lab television displays including interactive features in multiple buildings in Virginia Tech for increasing students' awareness of environmental issues. The research and education activities at the LEWAS lab have been supported by several grants from the NSF (example: NSF- Research Experiences for Undergraduates (REU) Site, NSF- Research Experiences for Teachers (RET) Site, NSF-TUES). [32, 33]

With its multitude of diverse activities, the LEWAS lab has attracted several undergraduates from all over the campus of Virginia Tech to work in the lab during the academic year. Until now, a total of 18 undergraduate students have gained research experience from the lab during the academic year, and 13 REU fellows have gained experience during the summer months. They were motivated to join the lab for several reasons, including gaining interdisciplinary research experience, experiences outside the classroom, real-world experience with environmental engineering, and coding experience in an interdisciplinary context. The LEWAS

lab provides these undergraduates an opportunity to be involved with various experiential learning experiences including interdisciplinary real-world research projects with team members from multiple disciplines, to gain experiences outside their own disciplines. This has aided them in developing diverse academic and professional skill sets as they have been exposed to research areas outside their areas of expertise. For the purpose of the paper, five undergraduates from the lab have shared their experiences in order to provide an overview of the types of activities the undergraduates are involved with and to highlight the benefits that undergraduates achieve by engaging in such an interdisciplinary research lab.

2. Literature review

The term 'interdisciplinary' is variedly used in practice, however following trends in the literature, interdisciplinary can be defined as a method to bring together several disciplinary perspectives and integrate them to form a comprehensive perspective, which can then aid in solving a problem, answering a question or addressing an issue that is too broad to be sufficiently dealt with within one disciplinary perspective.[34] Integration can be of concepts, procedures, methodologies and even data and knowledge.[35] The terms 'interdisciplinary' and 'multidisciplinary' are closely related. However they are not the same. For solving multidisciplinary problems, different disciplinary perspectives are required but the integration of the disciplinary perspectives is not essential. Multidisciplinary teams consist of people from various disciplines within the domain of engineering. In contrast, interdisciplinary teams can be comprised of engineers as well as non-engineers.[34] However, in both interdisciplinary and multidisciplinary work people need to collaborate across disciplines. In this regard, the report on "The engineer of 2020: Visions of engineering in the new century" has recommended engineering educators to introduce interdisciplinary learning in the undergraduate curriculum, so that students can develop the skill to work with people from different disciplines. [36] This will help engineers to address social, economic, and environmental concerns about an engineering solution, to work with people who define and solve problems differently and to collaborate with multiple cultures across nations.[34,37,38] Again, ABET under its student outcomes lists that engineers after their graduation should be able to work in multidisciplinary teams. [39] Thus, there is a significant requirement for undergraduates to develop the ability to work and communicate with people having different disciplinary backgrounds. Both interdisciplinary and multidisciplinary activities help students to develop the ability to communicate with other disciplines, understand the limitations of their own disciplines, appreciate other disciplinary perspectives and make connections across disciplines, which is termed as interdisciplinary competence.[1, 34] Experiences with these types of activities can further help students to integrate several disciplinary perspectives, which is essential for creating innovative solutions for an interdisciplinary problem. For the purpose of this paper, the term "interdisciplinary" is used to encompass both interdisciplinary and multidisciplinary experiences.

In this context, out-of-class opportunities can encourage students from multiple disciplines, having diverse skills and knowledge, to work together on an industrial, local or community problem.[34] Constructing knowledge and meaning from such real-life experience is known as experiential learning. In other words, experiential learning is elicited by doing authentic practices.[40] Experiential learning theories suggest an "orientation towards teaching and learning that values and encourages linkages between concrete educative activities and abstract lessons to

maximize learning".[41 p.239] Educational environments building on this theory encourage students to engage in real world problems where they can reflect on their learning experiences and knowledge gained.[42] By engaging in these learning activities, students can directly apply their theoretical knowledge and skills in a real-life context.[43] These experiential learning activities can include field site work, laboratory experiences, indoor and outdoor projects and other research work.[2] Thus, experiential learning is situated in a setting, which is relevant to the learner's future profession that furthers helps in developing transferable skills.[40] This theory also emphasizes that students' experiences will be reflected in their future engagements. For example, if students are engaging in research work and learning from that experience, then that would encourage them to consider research work as a future career option.[44] These types of undergraduate research experiences enhance the academic skills of the undergraduates. They also learn to communicate and develop relationships with people in their profession, which improves their professional skills.[45] These experiences prepare them for their future workplace environment. These undergraduate research experiences also aid students in gaining independent research skills and in experiencing graduate life with their graduate and faculty mentors.[3, 46] In the literature on undergraduate research experiences, several researchers have also identified that undergraduate research experiences lead students to pursue graduate education and have a lasting impact on their career and academic decisions.[47]

3. Undergraduate Experiences in the LEWAS lab

The undergraduates recruited at the LEWAS lab come from diverse disciplines and different academic levels and have various levels of experience of working in the lab. Five undergraduates have been chosen to provide specific examples from their experiences. The diverse background of these undergraduates is shown in Table 1. As undergraduate research assistants, they are engaged with various researches, service and outreach activities of the lab. The research work is related to the bigger research goals of the lab and also aligns with the individual research interests of the undergraduate students. This research work defines their primary area of contribution in the lab, which is visually shown in Figure 2. The service activities are for maintaining the systems of the lab and for attaining the lab goal of bringing the LEWAS lab into various engineering and non-engineering courses both inside and outside Virginia Tech. The outreach activities are aimed towards educating the community about environmental issues and watershed health. Below, the research, service and outreach experiences of the five undergraduates are described to highlight their involvement with the LEWAS lab.

Table 1. Background of the LEWAS lab undergraduates

Undergraduates	**Academic Levels when they were engaged in LEWAS lab**	**Current Department**	**Year/s of Experience**	**Average Number of hours spent per week**
3rd Author *	Freshman to 1st year of master's degree	Civil and Environmental Engineering	5 years	8-10
4th Author *	Sophomore to Junior years	Computer Science	1.5 years	8-10
5th Author *	Sophomore to Junior years	Biological Systems Engineering	2 semesters	8-10
6th Author	Freshman to Sophomore years	Computer Engineering	1 year	5-6
7th Author *	Junior to Senior years	Electrical Engineering	2 semesters	5-6

**The undergraduate students, who are continuing to work in the lab.*

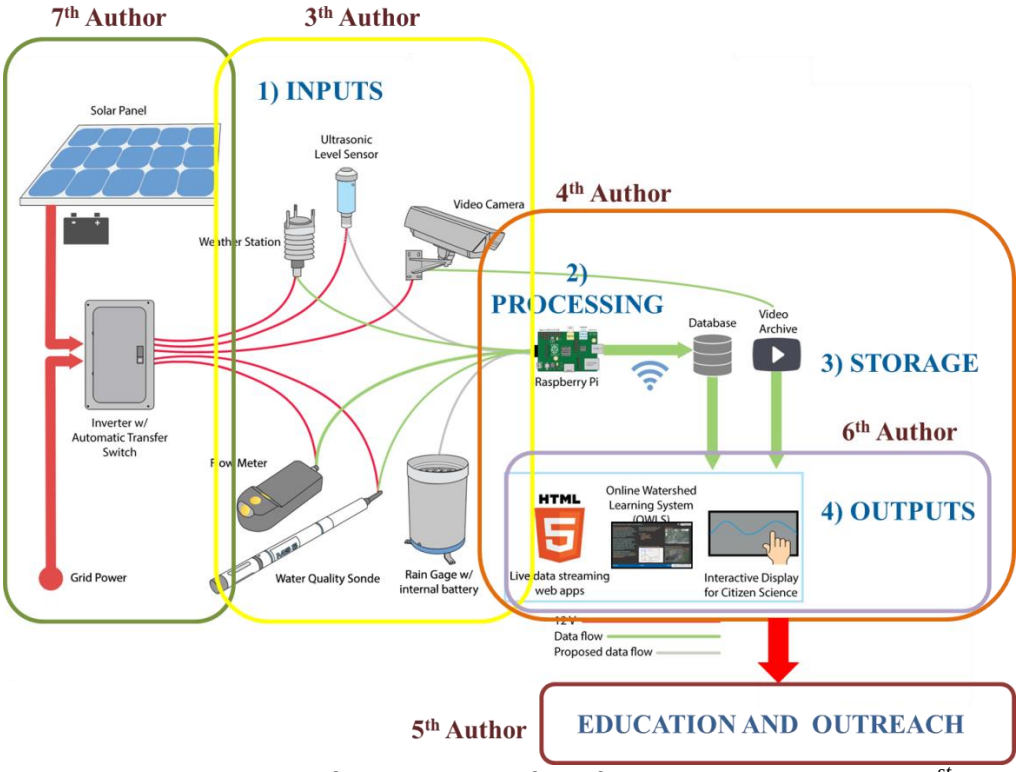

Figure 2. Primary areas of contribution of the five undergraduates (*The 1st and 2nd authors are a graduate student and post doc, respectively in the LEWAS lab looking over the full system and mentoring these undergraduate students, and the 8th author is the director of the LEWAS lab.*)

The third author had been associated with the LEWAS lab for 5 years, starting from the freshman year of his undergraduate degree in civil and environmental engineering at Virginia Tech. As an undergraduate researcher, he learned to analyze high frequency water quality data and assisted in developing several case-studies of the lab. His research focuses on the stage 1 of LEWAS, which are the instruments as shown in Figure 2. In one of his research, he capture the acute hydrologic and hydro chemical stream processes.[48] For his service to the lab, he periodically calibrated the LEWAS lab instruments to maintain the accuracy of the sensors, updated the LEWAS lab website, and created several informative videos for outreach and classroom activities of the lab, e.g., (https://www.youtube.com/watch?v=rS6cWdCgK3A). Following his senior year, he traveled to the University of Queensland (UQ) to assist researchers installing a LEWAS lab-style system in a small lake on campus. Currently, he is continuing as a first year masters' student in his discipline. From his years of experience in the lab, he has become adept in troubleshooting any sensor related issues in the LEWAS lab. He is pursuing his research in tracking illicit discharges with real-time high frequency water quality sensors. He is also engaged in mentoring undergraduate students' work in the lab.

The fourth author, who has background in Computer Science, has been involved with the LEWAS lab activities for more than one and a half years. He primarily works on the computer systems in the lab as shown in Figure 2. For his research, he explores various programming languages and gains experiences by developing and maintaining the software components of the LEWAS lab. These developments include, adding features to the LEWAS lab API, updating and maintaining the database, and developing an email notification system for detecting unusual events at the field site. He takes the lead responsibility to ensure that the system remains live. Along with these tasks, he responds to the programming-related requests of the lab members, helps in implementing the outreach activities of the lab. In the Spring 2017 semester he is also engaged in a LEWAS lab-based independent study course.

The fifth author comes from a Biological Systems Engineering background and has completed two semesters as an undergraduate research assistant in the LEWAS lab. She has been continually growing and expanding her research, service, and outreach work in the lab. She started working in the lab by developing and analyzing various case studies and maintaining and calibrating the instruments at the field site. Then she primarily focused on organizing and implementing LEWAS lab-based classroom activities and outreach events with the other members of the LEWAS lab as shown in Figure 2. For this purpose, she created multiple educational and informative videos and presentation materials. She also assisted in developing the LEWAS lab-based hands-on activities for various levels of students, ranging from elementary school student to freshman engineers, non-engineers and parents in surrounding communities. She also provided service in organizing the physical and electronic lab documents and actively handled the twitter account of the lab. Her outstanding work has led to her selection as the Virginia Tech representative to compete for a national Udall Undergraduate Scholarship in Spring 2017.

The sixth author, coming from a Computer Engineering background, was involved with the lab for two semesters and was also an REU fellow in 2016.[49] As a freshman undergraduate researcher, he started learning the programming languages for designing web user interfaces. He

significantly contributed towards advancing the OWLS with new interactive data visualization features by implementing the D3 library of JavaScript. The developmental work was pilot tested with several undergraduates to find its effectiveness and to receive feedback from its users. Utilizing his skills in designing web user interfaces (Figure 2), he also updated the other web user-interfaces of the lab, such as the interactive display and the LEWAS lab website. Similar, to other undergraduate researchers, he also participated and assisted in implementing several outreach and classroom activities.

The seventh author has been working in the lab for almost two semesters. With his background in electrical engineering, his work primarily focuses on the electrical circuits and powering system at the field site as shown in Figure 2. He started his research by deciphering the circuit at the field site and drawing it out with the LT-Spice software. Subsequently, he removed the unnecessary wiring at the field site and organized the circuit according to the circuit diagram he developed. He is currently exploring power monitoring systems, so that the solar and grid power utilizations of the LEWAS lab can be measured and monitored through the OWLS. This will help in making the system more robust, and the data will be used to build solar power case-studies. For his service, he investigates any electrical issues of the lab and helps in maintain the inventory of the lab.

4. Undergraduates' benefits from their interdisciplinary research experiences

Undergraduates in this interdisciplinary lab work closely with each other in a collaborative environment, which allows them to learn from each other. The various benefits gained by the undergraduates by engaging in this LEWAS lab are described in the remainder of this section.

4.1 Interdisciplinary experiences gained by the undergraduates

The undergraduates get the opportunity to be involved with various real-world research projects. Primarily, the undergraduates focus on tasks related to their disciplines, but they need to collaborate with others lab members from other disciplines to be able to solve problems. For example, the sixth author, having his background in computer engineering and working on web user interfaces, had to learn about sensors from the third author, who has his background in civil engineering. This helped him to design the appropriate data visualization features within the OWLS. The sixth author also had to learn how to create surveys and analyze the data from his graduate mentor from an engineering education background, as he wanted to test the usability of the new feature he developed in the OWLS. Thus, the sixth author had to draw upon multiple disciplinary perspectives to be able to complete his work.

Apart from being involved with interdisciplinary projects in the LEWAS lab activities, the undergraduates gain exposure to a variety of disciplines outside their own domain. According to the third author, as a civil and environmental engineering student, he would not have been exposed to electrical, computer systems and communication platforms through his disciplinary courses. However, through LEWAS lab activities, he became familiar with microcontrollers, data acquisition units, programming languages, databases, etc. Similarly, the seventh author is learning about environmental parameters and other hydrologic concepts, while conducting his investigation into power utilization in the system. Therefore, this interdisciplinary lab helps

students to gain experiences and knowledge beyond their own disciplines. In addition to having the privilege to learn from each of the other unique disciplines, the fifth author feels that by engaging in such interdisciplinary tasks, she got the opportunity to grow others' education by bringing her own unique discipline to the LEWAS lab. She finds this experience to be extremely valuable as she believes that she will encounter similar experiences in her work place environment, where she will be working with people from a variety of disciplines. As part of the interdisciplinary experience, LEWAS lab undergraduates present their work to an interdisciplinary group of audience during the weekly lab meetings. These meetings provide them the opportunity to learn how to answer various questions, which they might not have anticipated from their disciplinary audience. As a result, the undergraduates learn how to communicate technical details with people from other disciplines. They also learn about different disciplinary expertise and understand how each of these disciplines can contribute towards each other's discipline. These interdisciplinary experiences help undergraduates to value and respect others' disciplines.

4.2 Links between classroom learning and practical lab experiences

There is a positive relationship between what undergraduates learn in the classroom and their practical experiences in the LEWAS lab, which primarily focuses on three themes. Firstly, undergraduates are able to apply the knowledge they have gained in several courses to the LEWAS lab activities. For example, the seventh author utilized his knowledge from his course on AC and DC circuits in electrical engineering to decipher the LEWAS lab circuit and to use a multimeter in the lab, and his course on electronics has allowed him to understand how the solar and grid power work and how diodes play a role in the system of the lab. Secondly, the undergraduates realize connection between theoretical concepts included in their coursework and how those concepts are utilized in real-life. Calibration is a significant example in this case. Undergraduates from civil and environmental engineering, and biological systems engineering learn the importance of calibration and acquire some theoretical understanding of it. But, in the LEWAS lab, they are able to learn to conduct calibration and observe what happens if calibration is not properly carried out. At times, they also need to troubleshoot when the sensors do not respond properly. This provides them a real-life field experience. The fifth author, in her course on small watershed hydrology, gave an oral presentation about the LEWAS lab to show its application to the wide range of topics that they were covering in the course. She was able to show them the sensors and explain how the LEWAS lab uses a weir equation and the Doppler Effect to calculate water flow rate. This was extremely valuable to students in the class as they were now motivated to understand the concepts by observing that the concepts are actually being used in a real world setting to solve real problems. Thirdly, working in the LEWAS lab provides undergraduates with background knowledge for some of the future courses they plan to take. For instance, as the fourth author was dealing with the Linux infrastructure of the lab, he first encountered the fundamentals of process management, which was later reinforced in his computer systems course. Similarly, the sixth author got the opportunity to learn about data structure and to know how it is used in the LEWAS lab long before he took a course on data structure and algorithms. Therefore, the real-world experiences in the LEWAS lab have been helpful for the undergraduates in relation to their classroom learning.

4.3 Academic and professional skills gained by the undergraduates

The undergraduates develop many academic skills by engaging with the LEWAS lab activities. They explore new concepts, learn new things on their own, share ideas and ultimately solve the problem in a creative way. This provides them the opportunity to refine their skills as well as gain new skills. The LEWAS lab experiences have also helped undergraduates in adapting to situations where they have to learn new concepts on their own. The sixth and the seventh author say that they are now able to work independently and thus are more prepared for the workplace environment. To solve certain problems, such investigating an environmental event, the undergraduates even carry out more in-depth inquiries and interact with various professionals to gain additional knowledge. After gaining several such experiences from the LEWAS lab, the third author has now developed deeper perspectives on approaching problems. Working in the lab has helped the undergraduates to better understand the ways to conduct research, analyze data and implement field work.

An important aspect of the LEWAS lab is that it is a system that should always be online. For that reason, firstly, each of the components needs to be properly maintained. Secondly, if there are issues in any part of the system, they need to be addressed immediately. For both of these situations, students need to thoroughly understand the importance of each component and the technicalities behind it, so that any uncertain issue can be solved quickly. Being engaged with such a real-life system provides students both the deep knowledge needed to solve certain issues and an understanding of the practical implication of acquiring such knowledge. Students also gain skills needed to acquire new knowledge, if required, for addressing such issues. Gaining these varied experiences has helped the undergraduates of this lab to develop practical troubleshooting skills, which they would otherwise have had minimal exposure to.

Undergraduate students also have opportunity to develop professional skills. Firstly, by interacting with interdisciplinary team members, they learn how to communicate technical details with people from different disciplines. Secondly, by developing and implementing several classroom and outreach activities for different levels of students, undergraduates of this lab have developed skills to present technical content effectively to diverse audiences through oral presentations and/or videos. Thirdly, conversations and correspondence with a wide variety of professors and campus officials for LEWAS lab-based tasks have taught the undergraduates the appropriate communication skills for a professional setting. Fourthly, students are encouraged to document their work for future reference, which has helped them to develop their written communication skills. Finally, the undergraduates of the LEWAS lab have to work closely with other undergraduate team members and graduate students, which provide them with the opportunity to develop collaborative and cooperative skills.

4.4 Impacts of graduate and faculty mentoring on the undergraduates

Undergraduates of the LEWAS lab are always mentored by one or more graduate students as well as by the faculty members. Mentoring has played a significant role in assisting undergraduates to grow and progress within the lab as well as in their careers. For example, the fifth author’s mentors throughout her time in the lab have taught her the basics of how the lab operates, aided her in troubleshooting when things went wrong, and pushed her to explore areas

of the lab that she would be wary of exploring by herself. The presence of the mentors to provide constant feedback on their work and to address all of their concerns has positively impacted the undergraduates' learning in the lab. The seventh author adds that mentors are a constant system of support to bounce ideas off and to get help when they lack experience on a topic. Undergraduates of the LEWAS lab like that their mentors always encourage them to explore areas according to their interest. Mentors also help undergraduates to set goals for their projects and assist them to stay on task. The appreciation of undergraduate work and the recognition of their work to the professional space by the mentors aid in boosting their self-confidence and in increasing their motivation to learn and perform.

Additionally, the graduate and faculty mentors of the lab assist the undergraduates in their academic decisions. In this regard, the third author believes that the LEWAS lab team is an interdisciplinary group of people from which to ask questions about future plans, such as, an appropriate course that they might take, a scholarship for which they should apply, an internship they can pursue, etc. Mentors also write recommendation letters for the undergraduates for pursuing internships and for other applications. For example, the several mentors and the lab director wrote recommendation letters for the third author when he pursued an internship and applied to the graduate school.

4.5 Impacts on the academic and career decisions of the undergraduates

Several academic decisions of the undergraduates have been influenced by their experiences in the LEWAS lab. Firstly, by participating in several lab activities, they realize the need for certain coursework during their degree program. This led the third author to pursue a water resources and environmental engineering course during his junior and senior year, and the seventh author to take a course on renewable energy. Secondly, they now realize how a course might help in a workplace environment, or, in other words, they understand the applicability of the coursework. This helped the sixth author to grasp classroom content in a way that can aid in his future work. Now he perceives knowledge as a tool rather than a requirement. Thirdly, by observing the research work of the graduates and conducting their own research, the undergraduates have realized the potential and importance of research work. The fifth author says that it has opened her eyes to the opportunity of research either within industry or as a means to better understanding any subject. The fourth author now considers graduate education as his next academic goal, and the sixth author considers a master's degree as an option in his career. The research experience in the LEWAS lab has led the third author to pursue his master's degree, and his application essay for the master's degree program was based on his experiences in the LEWAS lab.

Similarly, working in the LEWAS lab has also impacted the career decisions of the undergraduates in different ways. For example the fifth author says that before entering the lab, she was unsure how she would connect her interest in engineering, her passion in the environment, and her unique skills in outreach and education. The lab has given her a concrete example of how she can connect all three of those interests into one cohesive position. To be able to convey the environmental engineering knowledge she understands and is passionate about to a wide variety of audiences through classroom and outreach activities has directly inspired her career goals. For the third author, the engagement with LEWAS lab activities has opened up

several career interests, one of which is to pursue a doctoral degree. From his experience, the sixth author realized that he performs better with deadlines and that he is more interested in joining industry than conducting research on his own. Thus, engagement with a research lab like LEWAS lab can inform the future career choices of the undergraduates.

Conclusion

We have discussed practical benefits that undergraduate students gained as part of their participation in an interdisciplinary lab. The personal experiences of 5 undergraduate researchers are documented, which included understanding other disciplinary perspectives and integrating them to solve problems, applying theoretical knowledge to practical problems, learning to explore research topics independently, troubleshooting practical engineering problems, refining written and oral communication skills with their peers, with professionals and among people from other disciplines, working in collaboration with other team members, having support for problems that arise in research and receiving guidance for career and academic decisions. These research experiences also lead undergraduates to get opportunities for internships, apply for scholarships and be recognized in several professional domains, and expose them to research opportunities such as the NSF program on Research Experiences for Undergraduates (REU) Site and International Research Experiences for Students (IRES). Overall, in the LEWAS lab, the undergraduates develop a sense of belonging, as they define the objective for their research projects, work as a community with fellow undergraduates, graduates and faculty, and flourish in a culture that boosts their professional and academic goals. With such experiential learning experiences, undergraduates become better prepared for future positions in academia and industry.

Further, we have also been successful in recruiting volunteers at the lab. This is mainly attributed to the contacts made by our undergraduate researchers. Moreover, we keep implementing LEWAS lab-based activities in courses in different disciplines to expose students to application of the high-frequency real-world data, which further helps in student recruitment. For example, implementation of a LEWAS lab-based project in an industrial design course led an undergraduate from that course to join the lab as a volunteer. Finally Virginia Tech's recent efforts in enhancing experiential learning opportunities for students is providing added motivation to our team in diversifying our lab's research and educational activities.[50]

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