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Opinion

Experience with Active Learning: The Charleston, SC, USA Urban Heat Island Effect

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Abstract

The urban heat island (UHI) effect is not well understood, especially within the cityscape. This editorial is from the perspective of an undergraduate student Cadet Emma Larsen, as she comes to understand the UHI through mentorship from professors Simon Ghanat and Scott Curtis, personal experiences as a cadet at a military academy in Charleston, SC, USA, and active learning through participation in a national heat observation campaign, the NOAA HeatWatch, and related independent research. HeatWatch seeks to understand the spatial variability of heat and humidity through citizen science. Volunteers fan out over a city three times in one day and collect information through car-mounted sensors. All the authors participated in data collection and team meetings, but this was the first time the student was exposed to project development across multiple institutions and realized the benefits a coordinated scientific endeavor has on her community. Finally, the student participated in her own heat study on the campus of The Citadel and gained a better appreciation of the relationship between land cover and geography on micro-scale temperature variability.

Keywords
Active learning; micro-climate; undergraduate research; heat index; HeatWatch; military

1. Introduction

Undergraduate military student Cadet Larsen was recently introduced to the urban heat island (UHI) effect - or the occurrence of an overall higher temperature being documented in urban areas compared to their rural counterparts within the surface and canopy layers – through The Citadel's Summer Undergraduate Research Experience (SURE). In addition to the ability to participate in research that is important to the authors and their families, Larsen is an undergraduate Civil Engineering student at The Citadel and was interested in how heat varies so she can help fellow cadets and herself survive the Charleston heat as students wear grey woolen uniforms and stand outside for hours for parades.

Extreme heat is the leading weather-related cause of death in the U.S [1]. This is particularly of concern in urban areas due to the UHI effect. It is expected that by 2050 nearly 70% of the global population will live in urban areas [2]. A World Bank study [3] asserts that cities of 100,000 or more are expected to triple their built-up land area by 2030 in developing countries. The UHI is mainly caused by differences in the thermal characteristics between the urban and rural environments, urban pollution and anthropogenic heat released by urban activities and air-conditioning systems [4, 5]. The modified land surface in urban areas, compared to rural environments, affects the storage and transfer of heat. Anthropogenic heat, slower wind speeds and air pollution in urban areas also contribute to UHI [6]. Elevated temperatures from UHI, particularly during the summer, can affect quality of life. UHI impacts include a deterioration of the living environment, an increase in energy consumption [7], an increase in the concentration of ground-level ozone [8] and an increase in mortality rates [9]. Higher urban temperatures can also increase the formation of urban smog [10, 11]. Health risks are increased as the high smog concentrations combined with higher air temperatures trigger a range of medical complications, including respiratory difficulties and cardiovascular failures [12].

The UHI effect directly impacts Charleston, a city currently home to ~750,000 people. Charleston has roughly 1,900 households age 65 years or older and about 2,900 households living below the poverty line [13]. This indicates a population of roughly greater than 5,000 people are known to have a high vulnerability to the heat. Charleston also hosts an estimated 7.3 million tourists per year who may not be acclimated to the climate of the local area and are not knowledgeable of the risk of heat and solutions to accommodate the effect upon the human body.

The Centers for Disease Control and Prevention found that from 2004 to 2018 the recorded heat-related deaths in the United States were 10,527, an average of 702 per year [14]. Living in urban areas that are experiencing increased temperatures can raise the risk level of the occupants to these heat-related illnesses. Some communities such as the elderly, households below the poverty line, athletes, and children are more vulnerable to heat-related illnesses due to medical predispositions, increased heat exposure, and inaccessibility to mitigating technology, namely air conditioning.

The objectives of this undergraduate research were to (1) better understand the causes and impacts of UHI in the Charleston area, and (2) to introduce Cadet Larsen to the scientific method and to engage her in metacognitive skills.

2. Pedagogy Used in SURE Program

The faculty mentors and Cadet Larsen engaged in tasks to develop Cadet Larsen's research skills and competencies. These tasks included constructing literature reviews, generating research questions, reviewing ethical considerations, collecting, and analyzing data, and synthesizing new knowledge. Prior to the start of research, Cadet Larsen completed a pre-research assessment survey of her metacognitive skills (i.e., critical thinking and problem solving; intellectual development; ability to deal with obstacles; content knowledge and methods; nature of disciplinary knowledge; and practice and process of inquiry). Afterward, Dr. Ghanat and Cadet Larsen discussed the results of the pre-assessment survey. A weekly Zoom meeting served as a structured event that facilitated the one-on-one instruction. Cadet Larsen conducted the literature review and presented weekly findings to her mentors and planned future analysis. In addition to conducting research with faculty mentors, Cadet Larsen attended three SURE Program lunch meetings focusing on professional development, mentoring, and providing an opportunity for her to discuss research progress with peers. A Post-Research Assessment Survey was completed at the end of the SURE program. Changes in scores helped to determine growth and impact of the SURE program.

The undergraduate research was organized into four modules:

In Module 1, Cadet Larsen was provided background information about heat, humidity, heat index, wind, etc. Supplemental reading about urban heat island was also assigned.

Module 2 focused on reading and discussion of various research papers about UHI published in the literature. Cadet Larsen was assigned the reading for homework and prepared oral summaries of assigned readings.

In Module 3, a Micro-scale UHI study was conducted on campus of The Citadel.

Module 4's focus was the analysis of data and report writing.

A list of various undergraduate research activities is presented in Table 1.

Table 1 List of pedagogical techniques used in SURE Program.

Activities/Assignments
• Larsen received help from the faculty mentors and developed a research proposal. The proposal and application were submitted to the Summer Undergraduate Research Experience (SURE) Program.
• Research proposal was accepted.
• Prior to the start of research, Larsen completed a pre-assessment of her metacognitive skills.
• Larsen and a faculty mentor discussed the results of the pre-assessment.

- Larsen was provided the background information about heat, humidity, heat index, wind, etc. Supplemental reading about urban heat island was also assigned.
- Mentors provided Larsen guidelines for the next steps in the research.
- Assisted Larsen to find research literature. Larsen conducted a review of relevant literature.
- Larsen discussed the literature review with her faculty mentors.
- Larsen attended the first SURE Program lunch meeting focusing on mentoring and discussed her research progress with peers.
- Mentoring via Zoom-the graduate school application process was discussed. Mentors communicated theories, methods, and everyday experiences of working in their disciplines
- After the first month of research, mentee completed the mid-assessment of her metacognitive skills.
- Larsen and a faculty mentor discussed the results of the mid-assessment.
- Larsen designed a micro-scale study of UHI at the campus of The Citadel.
- Larsen collected temperature, humidity data at several locations on campus.
- Larsen attended the second SURE Program lunch meeting focusing on professional development and discussed her research progress with peers. Staff from the campus Multimedia Services Office conducted a poster preparation workshop in which they taught the basics of designing a research poster.
- Larsen analyzed the collected data from the micro-scale study.
- Larsen participated in several Charleston HeatWatch design planning meetings sponsored by NOAA and CAPA Strategies.
- Larsen participated in training session for the data collection day (learned about data collection tool and the process)
- Larsen collected data for the HeatWatch program in the morning, afternoon, and evening of July 31.
- At end of summer, Larsen completed the post-assessment of her metacognitive skills.
- Faculty mentor and Larsen discussed the results of post-assessment.
- Larsen prepared a poster and presented her work at The Citadel research symposium.
- Larsen submitted an abstract for an oral presentation of her work to the 2021 Southern Conference Forum at Wofford College, SC.
- Larsen presented her research at 2021 Southern Conference Undergraduate Research Forum at Wofford College.
- Larsen attended the 2022 American Society of Engineering Education-Southeastern Section Conference and presented her poster, which opened great networking opportunities.

2.1 The 2021 Charleston HeatWatch Experiment

HeatWatch is a national effort to record temperature and humidity in participating cities on a single day to see how they vary from one area of a city to the next. Through this effort, the data collected about heat within the city can be formed into maps visualizing how the temperature varies throughout the urban area, how the layout of the structures causes this variation, and which communities are most vulnerable (see Figure 1). The national HeatWatch campaign is coordinated by NOAA and CAPA Strategies. They provide the sensors to local companies, organizations, and volunteers within the selected city to conduct the campaign themselves. For Charleston, the head of this campaign was Dr. Janice Barnes, of Climate Adaptation Partners. She led a group of local organizations including the City of Charleston; Medical University of South Carolina Arboretum, Institute for Air Quality Studies and Office of Health Promotion; Citadel Near Center for Climate Studies; Charleston Resilience Network; Charleston Medical District; South Carolina Interfaith Power and Light; and Carolinas Integrated Science Assessment. For the collection day, many volunteers were needed to drive throughout the city on preplanned routes with a sensor on their cars to gather the data. In all Charleston's HeatWatch had 18 routes, 27 volunteers, and 57948 measurements. While members of the organizations participated in the data collection, most volunteers were members of the community interested in helping discover more about Charleston's climate.

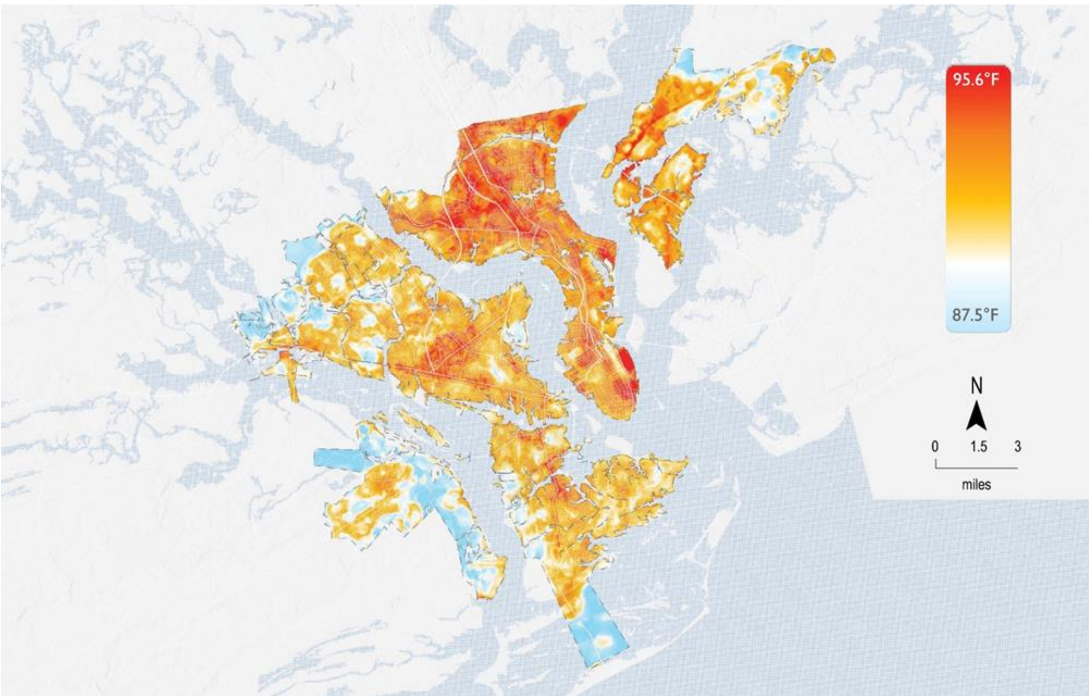

Figure 1 Temperature values (Fahrenheit) recorded by the NOAA HeatWatch experiment in Charleston, SC on July 31, 2021, at 3:00-4:00pm EST. Figure courtesy of CAPA Strategies, LLC.

Cadet Larsen was excited for HeatWatch to be her SURE project, because not only would this effort allow her to participate in undergraduate research, but it offered a highly unique experience of partaking in a much larger endeavor that differs even from her fellow SURE peers. Larsen was put into contact with Dr. Barnes, who involved the authors as representatives of The Citadel in the planning effort and participated in online conference calls, organizational emails, volunteer recruiting efforts, and data collection for Charleston HeatWatch. For the collection day, the authors drove in their cars on pre-planned routes within the city with a heat index sensor attached to their windows. For Larsen's experience in participatory learning, in addition to the in-depth learning she achieved from her research, she gained experience with major project planning, how a multi-company endeavor is planned and coordinated, and knowledge of how grand climate issues can be addressed within a community.

2.2 Heat on College Campus

While participating in the HeatWatch, Cadet Larsen became interested in how the intra-urban heat effect has manifested on her college campus. Although the urban heat island effect predominately refers to the ambient temperature of the entire city, a phenomenon associated with it is the intra-urban heat island effect that describes how smaller areas of a city or landscape become warmer due to the specific structure layout, sunlight exposure, and material. Larsen and her fellow cadets have always noticed specific areas around campus that the heat can be felt more intensely than others. To quantify the difference, Larsen conducted a smaller-scale heat mapping survey of her own on July 25, 2021, from 2:00pm to 3:40pm EST. Using a handheld sensor that records wind speed, temperature, humidity, and heat index supplied by Curtis, she walked to different locations around campus and recorded the data for that point. She started in a central location to create a reference point and while analyzing the data, she based her values on whether the temperature was higher or lower from the reference point. In additional notes, she recorded the time, GPS coordinates, type of surface material, and how the surrounding landscape was structured. The original starting point (1) was located on Summerall Field (Figure 2). Figure 3 shows the difference from temperature compared to the initial temperature measured along with the distance from the original location.

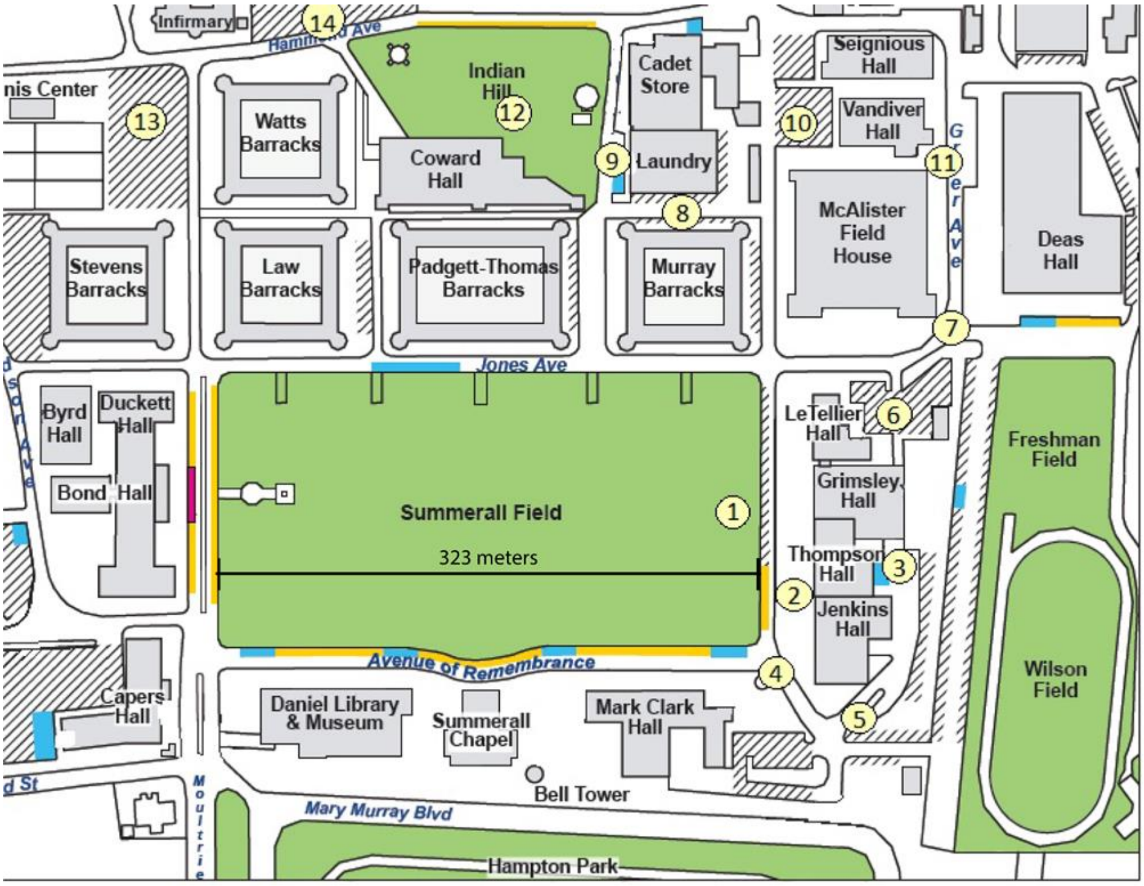

Figure 2 Locations on The Citadel campus where temperature data was recorded by Cadet Larsen on July 25, 2021 between 2:00 and 3:40pm EST. Numbers refer to the rank order distances from point 1. For reference, the width of Summerall Field is 323 m. Distances between Point 1 and the other observation points are given in Figure 3.

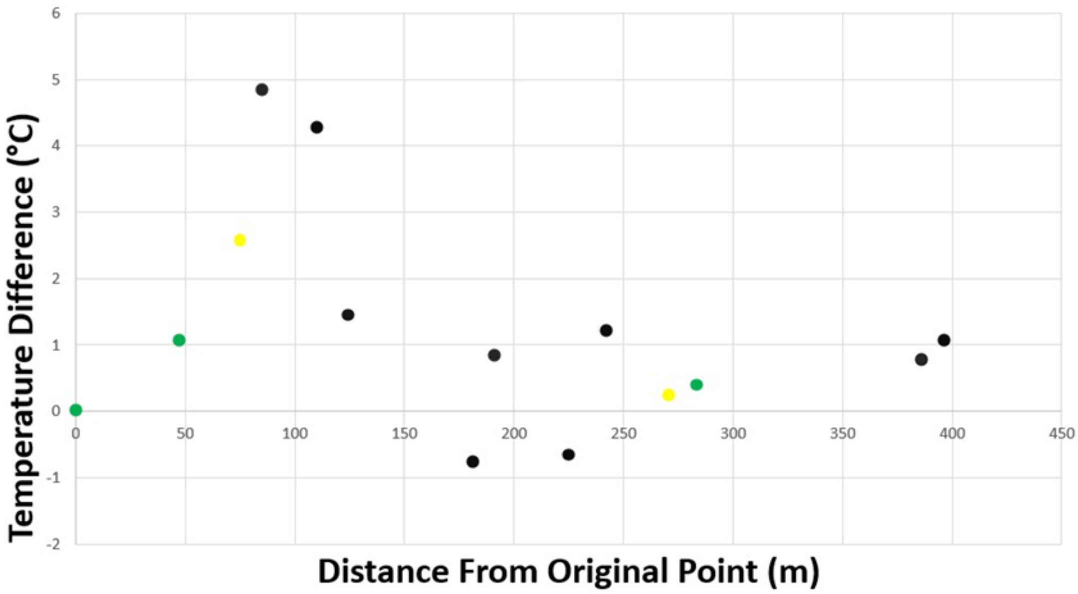

Figure 3 The temperature difference (degrees C) of different locations on campus compared to the distance (m) from the Original Point 1 (Figure 2 shows the locations).

Three different colors indicate what material the surface of the ground was at the point: green represents grass, yellow is concrete, and black is asphalt. They are also numbered by the shortest to longest distance from the reference point and correspond to the numbered locations on the map of the citadel campus provided below. The third point had the peak temperature at a difference of ~5 degrees Celsius and 85 m away from the reference point. The surface material is made of asphalt, as are many of the points with higher temperatures. Surfaces of the points recorded with the lowest temperatures were also made of asphalt (7 and 9 on Figure 3) but were located along north-south oriented roads and acted as urban canyons funneling winds from the Ashley River to the north of Figure 2, and effectively cooling down the ambient are temperature.

3. Discussion

The Citadel can help mitigate the increase in heat in the short term by practicing heat-related safety measures. By spreading awareness of the effects that heat can have on cadets, making sure cadets stay hydrated, and not having outdoor activities during black flag conditions will help to prevent the amount of on-campus heat-related illnesses. Strategies that The Citadel could take to help prevent major rises in heat may include planting more vegetation on campus along the sidewalks, creating green roofs, installing roofs with reflective material, and paving surfaces with reflective or permeable asphalt.

These techniques can also be used throughout Charleston to help mitigate the UHI effect. One of the most important parts of preventing drastic rises in heat is smart growth practices. Engineers have the training to combat temperature rise within cities by designing new structures with a focus on how they will affect the surrounding climate. As new structures are built and roads are being repaved, using materials and design shapes to prevent the absorption and encourage reflection of the sun's light are necessary. Engineers should also allot space whenever possible to vegetative cover as it is the most effective material for stopping temperature increase.

4. Conclusion

After being encouraged to read and study deeply into a topic, Cadet Larsen understood more about the UHI effect than she would have inside a classroom. The SURE program created a community of professors and students interested in studying beyond the expected curriculum and encouraged active participation instead of passive. There were not any quizzes or exams that created parameters of what Larsen was supposed to know. Instead, this was an educational experience without limits where students were given room to teach themselves and become subject matter experts on a topic.

Specifically, Cadet Larsen discovered what it means to participate in a large multi-institution research project and conduct her own UHI research. She found that the UHI effect is complicated as temperatures around campus depend on the land cover type, with asphalt being related to higher temperatures compared to grass, but she also learned that the nearby Ashley River has a moderating impact on temperatures. Validation of this work is underway [15], and Citadel students continue to investigate heat on campus as part of a larger effort by the HeatWatch partner institutions to sustain heat research in Charleston.

Overall, Cadet Larsen's research experience made her see the city in a different light and made her more aware of how small design choice can directly affect the climate. Larsen intends to take these experiences with her as she pursues a Ph.D. in Civil Engineering.

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Author Contributions

EL conducted the research and wrote the first draft of the manuscript. SG and SC provided inputs and edits. EL, SG, and SC all participated in the 2021 Charleston HeatWatch study.

Competing Interests

The authors have declared that no competing interests exist.

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