Analysis of Light Pollution on Allegheny College's campus

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and approved by the senior thesis committee.

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Abstract

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Title: *Analysis of Light Pollution on Allegheny College's campus*

Society is impacted by environmental conditions in a variety of unexpected ways. Many of these environmental conditions can be difficult to resolve because of the intricate details in each situation. Specifically, the environmental problem of light pollution has been gaining traction. Researchers attempted to build a design to figure out the impacts of light pollution in certain areas on Allegheny College's campus. A survey was distributed to see how the students on campus are impacted by light pollution. By accomplishing this, the relationship between light pollution and Allegheny's community will be better understood, and Allegheny will develop insight on some valuable ways to mitigate it, if necessary. In addition, I attempted to quantify the amount of light pollution by using a Sky Quality Meter and test whether the ambient outdoor lights were above standards for building certifications. In conclusion, researchers saw that the school's ambient nighttime light levels were below standards recommended by engineers for safety purposes. However, from the surveys it was determined that light pollution is a problem that students experience on campus, and they value safety and a dark sky uninhibited by light pollution. The components represent competing needs, and alternative solutions are required to mitigate light pollution on Allegheny's campus. More research must be done to better understand the complexities of this environmental problem.

Introduction

For thousands of generations, we have looked to the sky to guide us in our educational pursuits. Astronomy, the study of celestial objects, space, and the universe, has helped guide our natural curiosity to develop instruments and methods that help us answer questions about the way our universe works (Science Daily, accessed 2018, Rosenberg). Over time, the impact of artificial night lighting has been a growing concern for Astronomy (Longcore, 2004; Hölker, 2010; Beenie, 2014; Crawford, 2000, Narisada, 2001). Light pollution occurs during the night when the lights from artificial illumination are scattered through the atmosphere, making it more difficult to study the sky (Bennett, 2014). This pollution is increasingly making it more difficult for professional and amateur astronomers to see and monitor our universe (Riegel, 1973). According to the First World Atlas of the artificial night sky brightness, approximately one-fifth of the world population, more than two-thirds of the United States population and more than one half of the European Union population have already lost naked eye visibility of the Milky Way (Cinzano, 2001). However, light pollution impacts our world in many ways other than Astronomy. Light pollution can have distinct, negative social and environmental implications in addition to other economic, and health related consequences (Chepesiuk, 2009; Gaston, 2013; Navara & Nelson, 2007; Rich & Longcore, 2005; Riegel, 1973; Lowenthal, accessed 2018).



Figure 1: Sea turtles attracted to artificial light after hatching

One of the primary implications of light pollution corresponds to the environmental impact, specifically to environments in close proximity to urban settings. As a result, this impacts a large population of nocturnal animals and insects, by affecting mating, migration, foraging, reproduction, communication, and other behaviors in animal habits (Longcore 2004, Hölker 2010, IDA 2016, Vandernoot, West 2018). For example,

New York City experiences approximately 10,000 casualties among migratory birds relating to light pollution problems a year (Chepesiuk, 2009). About 200 different species of birds migrate at night over North America. Artificial light can confuse these migrants during passage from brightly lit buildings, communication towers, and other structures (Chepesiuk, 2009). As a result, they can become disoriented and crash or lose their way, which can ultimately impact population levels and diversity of species of songbirds in North America.

Similarly, approximately 30% of vertebrates and 60% of invertebrates are nocturnal worldwide (Hölker, 2010). This means that artificial nighttime lighting can impact a large percentage of organisms in the environment including sea turtles, insects, and small mammals. We can see these organisms being impacted by large populations congregating around light sources (see Figure 1). As these species congregate around these light sources, they become more vulnerable to predators such as birds and other carnivores or omnivores that they normally can avoid. This can ultimately alter insect biomass and the food chain, which can cause a loss of light-sensitive species in these areas (Hölker, 2010). Further, prolonged exposure to artificial light prevents many trees from adjusting to seasonal variations. As a result, this can have implications for the wildlife that depend on trees for their natural habitat (Chepesiuk, 2009).

Light pollution also has social consequences relating to the economy, human health, and safety. In terms of the economy, the United States is spending $7 billion a year extra from unused outdoor lighting (Gallaway, 2010). Around 6% of the energy produced in the United States goes to outdoor lighting, and about 30% of that energy is wasted through light pollution. Consequently, this waste of energy generated 66 million metric tons of CO_2 into the atmosphere, which is the equivalent of adding 9.5 million cars on the road (Gallaway, 2010, California Energy Commission 2005).

In regards to human health, studies have shown that increased nighttime bedroom illumination can reduce and delay melatonin production resulting in performance, alertness, sleep and metabolic disorders (Falchi et al., 2011, Gooley et al., 2011). In addition, different types of light tend to have different impacts on human health. Specifically, blue light with a wavelength between 470 nm and 525 nm can boost attention, mood and reaction times (Kayumov, 2005). Consequently, experiencing blue light before bed can be disruptive and can potentially increase the likelihood of developing cancer, diabetes, heart disease, and obesity (Harvard Health Publishing). Researchers have observed a decrease in melatonin production in

both humans and animals (Kayumov, 2005). Researchers have also observed that light pollution can disrupt sleep by interrupting light related circadian rhythms, which are internal processes that regulate sleep and eating patterns in living organisms (Chepesiuk, 2009, NIGMS, 2020).

Further, light pollution and safety can have a complicated relationship. Outdoor lights are associated with providing the community with safety at night, yet, there is no scientific evidence that nighttime lighting deters crime (Steinbach, 2015). In fact, there are many studies that show that there may be a relationship between brightly lit alleyways and crime, suggesting that brightly lit locations can contribute to higher crime rates (Morrow, 2000). As a result, many studies recommend following the guidelines to light these areas to the minimum needed to safely maneuver around the area according to basic lighting standards (IDA, 2020).

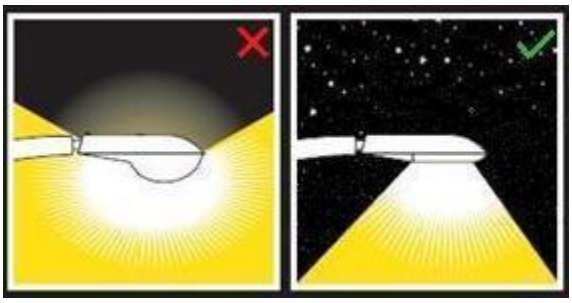


Figure 2: partially shielded vs. fully shielded street lamps

Although light pollution is increasingly becoming a popular discussion in the scientific community, many communities are unaware of this issue (Lyytimäki, 2011; Cinzano et al., 2001; Narisada and Schreuder, 2004; Chalkias et al., 2006; Smith, 2009; Hölker et al., 2010a). Organizations, including the International Dark Sky Association (IDA), have been developing initiatives to address the impact of light pollution, and raise awareness around this issue (Ashley, 2018). These programs advertise the use of light fixtures approved to have outdoor night lighting regulations and other light sources and promote education on the impacts of light pollution (Paige, 2017; Ashley, 2018). The IDA has established research initiatives, such as the "Globe At Night", to help mitigate the impacts of light pollution across the world. This program invites "citizen-scientists" to record their night sky brightness using the app, called the "Loss of the Night", to record their observations. These observations are stored on a database that can be used to see the impact of light pollution across the globe. This program has collected over 180,000 measurements over the past 12 years in over 180 countries (Globe At Night, 2020).

While there are many certifications and recommendations to mitigate light pollution, the IDA has provided a list of recommendations to keep in mind while taking action on light pollution. These recommendations include using fully shielded fixtures (see Figure 2), using

"warm white" or filtered LED lights to minimize blue emissions, using products with adaptive controls such as motion sensors, dimmers, and timers, turning off or dimming overnight, avoiding over-lighting, and only illuminating the exact amount of space that is needed (see Figure 3). There are there recommendations and certifications such as the LID certification that emphasize similar goals and regulations (IDA, 2020; International Astronomical Union, accessed 2018; Rinkesh, accessed 2018).

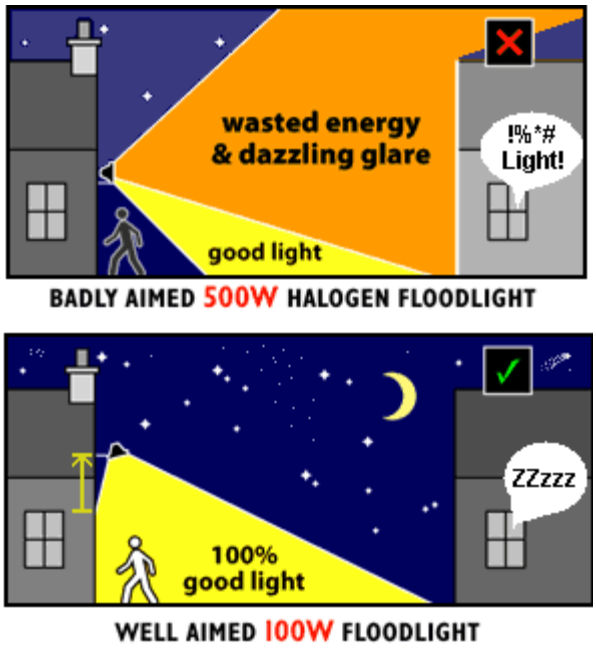


Figure 3: Example of downward facing street lamps

In addition, there are many standards for lighting such as a maximum 250 watts HID (High Intensity Discharge) for commercial lighting, maximum 100 watts incandescent bulbs, maximum 26 watts compact fluorescent for residential lighting, and making sure that lights are shielded so that light is not directly visible outside property perimeter (Vandernoot, Low Impact Development).

Light pollution is becoming an issue for schools and universities that are becoming interested in saving money and becoming more sustainable. Researchers from Truman State University carried out a study of light pollution in Kirksville, MO, a town similar in size to Meadville, PA (Kamp, 2017). The first major step for their project was to do basic research and collect data on light pollution in Kirksville. The student volunteers used light meters to figure out how much light is wasted on campus. With these data, they identified ways to lower the amount of light pollution. Researchers focused on replacing globe shaped fixtures with reflective covers direct the light to the ground.

At Nottingham University, a student astronomer engaged in a campaign to reduce campus light pollution. Researchers raised awareness of light pollution by taking pictures of the light pollution around campus. This was an important visual in helping individuals see what light pollution can look like in application on a campus. Researchers also provided ways to mitigate the light pollution seen campus. The study concluded that that there was an excess of outdoor lighting that can be seen through astrophotography. This could be caused by lights that were

bright and on for long periods of time. As a result, researchers suggested that motion sensors should be utilized and investing in outdoor lighting fixtures that don't direct light into your eyes (Smith, 2019).

A final light pollution study was done in Morehead, Kentucky, a small town with a population of about 7000 people. Researchers followed the procedure given by the "Globe at Night" protocol. They used a Sky Quality Meter (SQM), a device used to record the amount of light pollution across the town by measuring the sky brightness of visible light (wavelength of 400-700 nm) in magnitudes/ arcsec^2. They ultimately learned that light pollution in their small town was almost equivalent to the light pollution you can find in urban areas. (Birriel, 2010).

In 2020, Allegheny College, located in Meadville PA, has become the first school in Pennsylvania to become carbon neutral. In order to make that happen, the college been producing programs and projects across campus aimed to reduce the campus' carbon footprint. Some campus accomplishments include hiring a sustainability coordinator, creating an on-campus composting system, reducing the amount of waste, supporting sustainable buildings and architecture, and introducing wildflowers instead of lawn maintenance (Allegheny College Campus Accomplishments). Because of the increased interest of the community to become a green campus, light pollution is an environmental issue that should be addressed.

Allegheny College has been having issues with light pollution on campus in several different locations. Newton Observatory, home to our historic telescope with a nine-and-one-half-inch objective lens (Venecia, 2018), is located near street lights and building with internal light that can impact nighttime viewings of the sky. The study of the stars and other celestial objects require places that are free of air and light pollution because the scattering of the light causes makes it harder to see faint objects (Crawford, 2000).

Additionally, there are places on campus where energy can be saved. For example, in the Senior Circle, which is located right next to the Montgomery Gymnasium, there are multiple lights that are facing upward illuminating the sky. This can also be seen with the Robertson Athletic Complex, located north of campus, tends to have bright lights near the athletic courts, which can hinder a great setting for star-viewing. Solutions to these problems can include changing the light fixtures to be angled downward, changing the light frequency to be lower so that the wavelength of light is more in the red spectrum, and using stones or devices that reflect

moonlight instead of generating light (Paige, 2017; O'Connell, 2017; Ashley, 2017; Lowenthal, accessed 2018).

This project used several approaches to investigate light pollution impacts around Allegheny's campus. First, the amount of ambient outdoor light was measured using a digital lux meter. These results were compared to standards for urban pathways to understand if Allegheny's outdoor lighting levels are greater than the recommended building standards. Next, light pollution was measured using the protocols from the "Globe at Night " in magnitudes/ arcseconds^2. This required using the Sky Quality Meter to estimate the amount of light pollution and compared to other places globally. Finally, I sent out surveys to understand how light pollution is impacting campus life, and where the community wants to see improvement. From these components, the relationship between light pollution and the campus community will be better understood, and recommendations of improvements for administration and the student body can be provided.

Methods:

This section will describe the procedures for the three different components to this study: the digital lux Meter, the SQM (Sky Quality Meter), and the light pollution survey. Gathering these components will allow for an understanding of the quantity of outdoor nighttime illumination, if it's above building standards, and if it impacts the lives of students on campus.

Lux Meter



Figure 4: Lux Meter device

For this section of the aim was to figure out whether the ambient outdoor lighting on campus is higher than the standards for urban settings. In order to calculate this, a digital lux meter was used to record the amount of light during the new moon in Lux. The main areas of focus were Senior Circle and Newton's Observatory on campus (see figures below). Specifically, observations were made at four separate spots in each location (see A, B, C, and D in figures below). The sensors were placed on the ground to keep consistency. Afterward, the averages of the observations were calculated and compared them to the standards found for nighttime illumination. The standards are the minimum illumination required for engineers to adhere to when building. They come from the National Optical Astronomy Observatory (NOAO), and can be found in Appendix C. Many other organizations helped contribute to these standards including the IDA, the National Science Foundation, and the OSA Foundation. These standards are used in cities such as Los Angeles.



Figure 6: Measurement locations for Newton Observatory

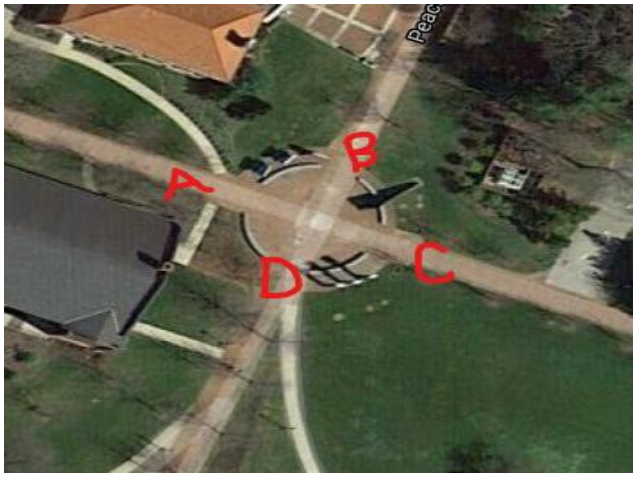


Figure 5: Measurement locations for Senior Circle

The Sky Quality Meter

To quantify the amount of light pollution on astronomy and nighttime visibility, the Sky Quality Meter (SQM) was used. The SQM is a device created to monitor light pollution in magnitudes per arcsecond^2, which is a measure of surface brightness, light intensity per unit area, used by astronomers. A SQM reading of 19 would correspond to a 19-magnitude-star smeared out across the sky for each squared arcsecond. Just like astronomical magnitudes, a SQM reading of a larger number means a darker sky, while a smaller reading would result in a brighter sky. Examples of SQM magnitude readings and what they would look like can be found in Appendix C.



Figure 7: Example of the Sky Quality Meter (SQM)

The guidelines given by the SQM manufacturer, Unihedron, were used at two locations: Newton Observatory and the Senior Circle using the same locations as the lux meter (see Figures above). This procedure was replicated three times on different nights for consistency. This same procedure has been used by other case studies (Birriel, 2010). The units of the data will be in visual magnitudes per square arc second (mag/arcs^2). The procedure is as follows:

- *Step 1: Find your latitude and longitude.*

- *Step 2: Go outside an hour after sunset (about 7-10 pm)*
    - *Observations should be taken on a clear night when the Moon is not up and when the Sun has set for at least an hour. The Sun and Moon would otherwise contribute to the SQM's sky glow reading*
    - *Leave the meter outside for at least 5 minutes to reach ambient temperature before taking any measurement*
    - *Avoid using the SQM or SQM-L near lights like streetlights and in areas that are shaded by trees or buildings. A rule of thumb for the SQM is to be as far from the object as it is high. For streetlights, stand at least 7.5 meters (or 25 feet) away, if possible.*
- *Step 3: Take a measurement*
    - *Point the SQM so that sensor/faceplate points toward the zenith. Press the red button once and release. Under urban skies, a reading will be displayed almost immediately. Under the very darkest conditions (no moon in the sky, far from civilization) the SQM may take up to a minute to complete its measurement. Please ensure that you maintain the orientation of the SQM until the reading is displayed. The SQM's reading is indicative of the sky brightness with a cone of half-angle 40 degrees centered on the faceplate perpendicular. There must be no direct illumination of the faceplate sensor by a terrestrial light source if the reading is to be meaningful. ✳ ✳ ✳ Typical Readings Magnitudes per square arc second is a logarithmic measurement. Therefore large changes in sky brightness correspond to relatively small numerical changes. A difference of 1 magnitude is defined to be a factor of $(100)^{1/5}$ in received photons. Therefore a sky brightness 5.0 mag/arcsec² fainter corresponds to a reduction in photon arrival rate of a factor of 100.*

Once the data have been gathered, the observations were compared to results found worldwide with the Unihedron Dark Skies Database (found here). These oberservations were compared to locations with similar parameters as Meadville, such as area, population, population density, and weather conditions. These included locations in Pennsylvania, West Virginia, Ohio,

and other states around the U.S. (see Table 1 in Results). From these data there will be a better understanding on whether or not light pollution is below or above average in these locations.

To determine if the average light pollution magnitude at Senior Circle and Newton Observatory are the same, researchers completed a two sample t-test using the following equation. The calculations can be found in the results section and the equation is as follows:

$$x_1 = average\ from\ Senior\ Circle$$

$$x_2 = average\ from\ Newton\ Observatory$$

$$n_1 = sample\ size\ from\ Senior\ Circle$$

$$n_2 = sample\ size\ Newton\ Observatory$$

$$s_1 = standard\ deviation\ from\ Senior\ Circle$$

$$s_2 = standard\ deviation\ from\ Newton\ Observatory$$

$$H_o: \underline{x_1} = \underline{x_2}$$

$$H_a: \underline{x_1} \neq \underline{x_2}$$

$$t = \frac{\underline{x_1} - \underline{x_1}}{\sqrt{\frac{(s_1^2)}{n_1} + \frac{(s_2^2)}{n_2}}}$$

In addition, the average expected magnitudes, x is the average of the values found at the Unihedron Database (see Table 1). This value comes from the average light pollution magnitudes found from locations similar to Allegheny College based on population, population density, and area. The observations from both Senior Circle (x_1) and Newton Observatory (x_2) were compared to this value using a two- sample t-test twice.

$$x = average\ from\ database\ observations$$

$$x_1 = average\ from\ Senior\ Circle$$

$$x_2 = average\ from\ Newton\ Observatory$$

$$H_o: \underline{x_1} = \underline{x}$$

$$H_a: \underline{x_1} \neq \underline{x}$$

$$t = \frac{\underline{x_1} - \underline{x}}{\sqrt{\frac{(s_1^2)}{n_1} + \frac{(s^2)}{n}}} =$$

Survey

In order to gauge the impact of light pollution on student life, researchers distributed a survey online through Google forms, My Allegheny, through the academic departments and the Resident Advisors, RA's, to send to their residents. All the records were saved on a Google sheets file and secured on a private laptop. The design of the survey can be found in Appendix D.

The main questions that were focused on being asked were:

- Have students heard about light pollution?
- Do students experience light pollution is on campus? If so, where?
- Is outdoor lighting necessary for safety?
- Does nighttime outdoor illumination impact students' daily lives?

To analyze survey results, researchers grouped the answers to the questions in categories to be able to analyze them better for the future. Specifically, open ended questions, such as "Where have you experienced light pollution on campus?" yielded responses that were variable. In order to efficiently analyze these questions, researchers grouped the results into categories: buildings (Residence halls: Baldwin, Brooks, the Delta Tau Delta Fraternity House and Academic Buildings: Pelletier Library, the Campus Center, Vukovich, Bentley), outdoor lighting fixtures (Senior Circle, N. Main, Gator Quad, the water towers, Brooks Walk), stadium lights (Robertson), and none (no observed light pollution, or confusion). In addition, for other research questions, researchers calculated the frequencies of the responses to the questions. For example, "Outdoor lights are necessary for safety" yielded responses: strongly disagree, disagree, neutral, agree, strongly agree. The frequencies of each response were taken, and then divided by the total amount of responses to generate a percentage for each response. These are the results given in the next section.

Results

Lux Meter

After using the Light Sensor, there seems to be no significant readings of light pollution in either the Senior Circle or the Newton Observatory on Allegheny College's Campus. Specifically, after using the digital lux meter, it is apparent that the light levels were too low to register on the lux meter. This could indicate that the observations are actually below the building standards for urban pathways.

Sky Quality Meter (SQM)

Location	Senior Circle	Newton
Average	16.35	15.95
SD	0.2313	0.7945

On a scale from 1 to 21, the average measurement of light pollution in mag/arcsec^2 is approximately 16.35 for the Senior Circle and 15.95 for the Newton Observatory. After completing a 2- sample t-test:

$$H_o: \underline{x_1} = \underline{x_2}$$

$$H_a: \underline{x_1} \neq \underline{x_2}$$

$$t = \frac{\underline{x_1} - \underline{x_2}}{\sqrt{\frac{(s_1^2)}{n_1} + \frac{(s_2^2)}{n_2}}} = 1.6745$$

$$degrees\ of\ freedom = 3$$

$$t_{critical} = 2.353\ (for\ 95\%\ confidence)$$

Thus, we can accept H_o and we can conclude that there is no significant difference between the means of these two samples. As a result, the light pollution in these two areas can be thought of to experience light pollution equally at different locations on campus.

Name	Location	Condition	Magnitude
Kilbourne Observatory	Sunbury, Ohio	clear	16.18
Cherry Springs	PA	10% cloud cover	23.27
Burlington	MA	10% cloud cover	14.01
Troy Hill	Pittsburgh, PA	Clear	18.24
PA Ranger Station	French Creek State Park	Clear	19.78
State Game Lands 43 rifle range	Chester County, PA	Clear	19.82

Table 1: 6 locations from the Unihedron Database. The average magnitude is x= 18.55, and standard deviation s= 3.21.

Table 1 depicts handful of locations similar to Meadville, PA based on population, population density, and area. The average of these observations can act as a standard for measured light pollution, and two 2-sample t-tests can be completed using the data from both Senior Circle and Newton Observatory. This will tell us whether these locations have similar levels of light pollution compared to locations similar or close to these observations. The process is as follows:

$$x = average\ from\ database\ observations$$
$$x_1 = average\ from\ Senior\ Circle$$
$$x_2 = average\ from\ Netwon\ Observatory$$

$$H_o: \underline{x_1} = \underline{x}$$

$$H_a: \underline{x_1} \neq \underline{x}$$

$$t = \frac{\underline{x_1} - \underline{x}}{\sqrt{\frac{(s_1^2)}{n_1} + \frac{(s^2)}{n}}} = -2.434$$

$$H_o: \underline{x_2} = \underline{x}$$

$$H_a: \underline{x_2} \neq \underline{x}$$

$$t = \frac{\underline{x_2} - \underline{x}}{\sqrt{\frac{(s_2^2)}{n_2} + \frac{(s^2)}{n}}} = -2.712$$

$$degrees\ of\ freedom = 5$$

$$t_{critical} = 2.571\ (for\ 95\%\ confidence)$$

Thus, we can accept the null hypothesis for the Senior Circle and reject the null for the Newton Observatory. This is contradictory to the results talked about earlier. This means that the light pollution seen at Senior Circle and Newton Observatory may not be consistent with areas similar to Meadville. Overall, the value of light pollution seen on Allegheny's campus I smaller, meaning that it is brighter that the ones seen on Table 1.

Survey

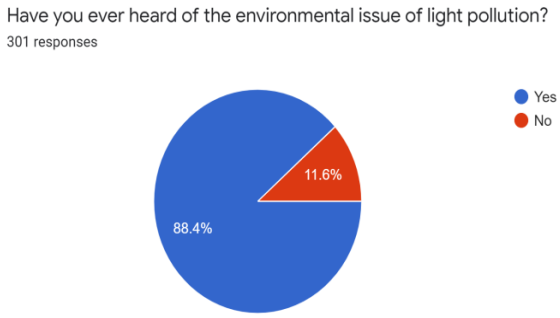


Figure 8: Results from survey questions "Have you heard of the environmental issue of light pollution?"

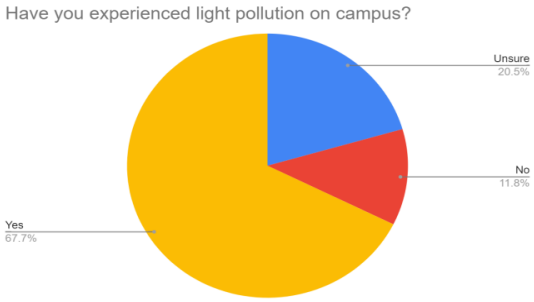


Figure 9: Results from the respondents who answered "yes" to knowing about light pollution

The survey received 301 responses. Of the responses 226 respondents reported a basic understanding of light pollution prior to engaging with the survey. Of those respondents that reported knowing about light pollution 182 reported experiencing light pollution on campus, 82 were unsure, and 34 reported not knowing about it at all.

In addition, a majority of the respondents (more than 50%) agreed or strongly agreed with the statements: "Outdoor lighting is necessary for safety," "Nighttime lighting interrupts my extracurricular activities," and "Experiencing a night sky that is not influenced by light pollution is important to me." Further, the locations that people experienced light pollution the most were skewed towards buildings such as the Pelletier library, Bentley, the campus center, and other residence/ academic/ administrative buildings. Other honorable mentions include the outdoor light along N. Main Street, Senior Circle, and the Gator Quad.

Responses indicate that the locations that are most easily associated with light pollution are Robertson Athletic Complex, Senior Circle, and outside of residence halls including

Baldwin, Brooks, the Delta-Tau-Delta Fraternity House, and Theta Chi Fraternity House. Locations that were popular were not anticipated prior to the surveys include Brooks walk and the Gator Quad. Based on the results from the survey, locations where light pollution needs to be addressed are Robertson Athletic Complex, the Gator Quad, and outside of Residence Halls.

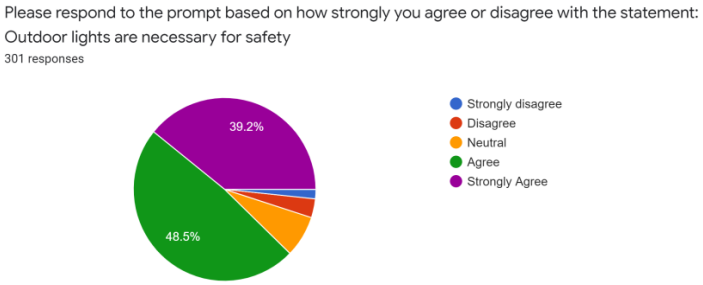


Figure 10: Results from survey question #6.

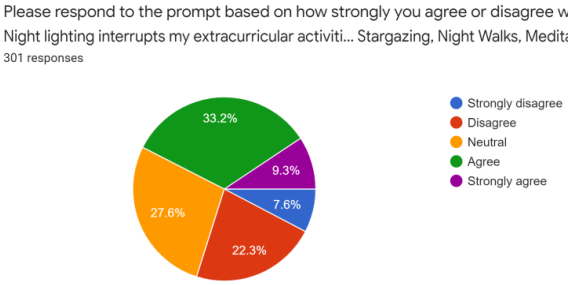


Figure 12: Results from survey question #5.

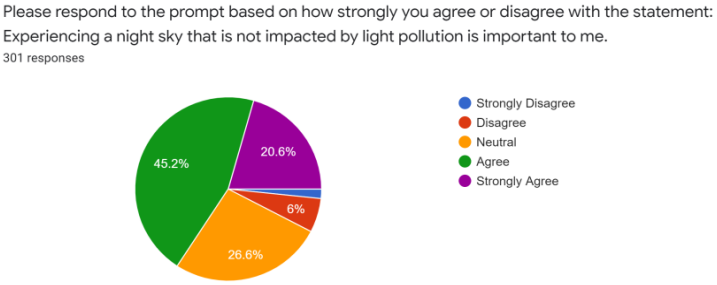


Figure 11: Results from survey question #7

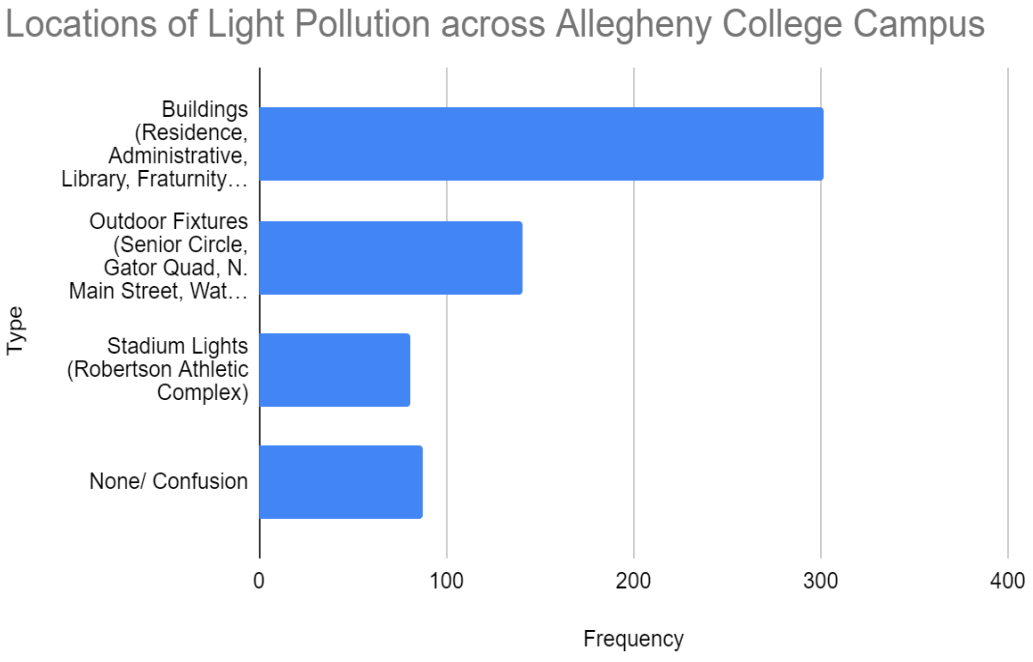


Figure 13: Observations of locations impacted by light pollution reported by students of Allegheny College. Results from survey question #4 separated into four categories: ambient light coming from buildings, outdoor fixtures, stadium lights, and none. Residence halls: Baldwin, Brooks, the Delta Tau Delta Fraternity House, and Theta Chi Fraternity House. Academic Buildings: Pelletier Library, the Campus Center, Vukovich, Bentley. Outdoor lighting fixtures: Senior Circle, N. Main, Gator Quad, the water towers, Brooks Walk. Stadium lights: Robertson. None: no observed light pollution, or confusion.

Discussion

Are Allegheny's outdoor light levels above the building standards?

To measure ambient outdoor lighting, I used a Lux Meter Device. The devices that were used could not identify an excess amount of outdoor lights surrounding the Senior Circle and Newton Observatory. As a result, the amount of ambient light incident on sidewalks is approximately zero. In comparison, the recommended lighting (see Appendix C) for urban outdoor lighting is around 7.8 Lux. These recommendations are meant to represent the minimum amount of light needed to efficiently use the space at night. Based on the observation collected through this study; we can conclude that the light pollution on campus is below the standards that are recommended for nighttime outdoor lighting. As a result, in terms of building standards, Allegheny College seems to be doing a good job with handling light pollution.

One potential explanation for these readings could be user error with the Lux Meter Device. If the device was held at the wrong orientation, it is possible to collect inaccurate results. Another solution could be that the device used was not strong enough to detect the indirect light from the fixtures. As a result, I would recommend for this procedure to be replicated with other devices for future research. Another reason could be that Senior Circle and Newton Observatory are locations on campus that have no direct nighttime purpose. For example, the Robertson Athletic Complex may have more light pollution because these areas may be utilized at night by the school's athletic teams. Thus, the lights have mandatory requirements to be utilized. Currently, the relationship between necessary lighting for safety in the aspects has not been determined, and future research should focus on understanding if the required lighting at specific parts on campus is necessary.

Is there significant light pollution measured near Senior Circle and Newton Observatory?

The recorded light pollution measurements in Senior Circle and Newton Observatory are 16.35 and 16.71 magnitudes per arc seconds^2 respectively. These values stand for the average light pollution, measured in magnitudes per arc second squared over a period of 4 days. Each recorded day was overcast, so the phase of the moon was not taken into consideration. A value of 16 corresponds to an evening with a full moon or immediate overhead outdoor lighting. This is the magnitude that we would expect to receive in a suburb close to a major city such as New York or Boston.

The results across the SQM are consistent in concluding that the light pollution is similar to suburbs of large city. However, Allegheny College is in the small town Meadville, Pennsylvania. Meadville has a population of about 13,000 people over an area of 4.38 mi^2 (Meadville, Pennsylvania Population 2020). This gives us a population density of around 2900 people/ mi^2. We can use the population density to compare the amount of light pollution that the area contributes to. Comparably, the population of New York City has a population density of around 29000 people/ mi^2 (Maciag, 2020), which is ten times as large as Meadville. Meadville also appears to be experiencing more light pollution than other locations in the region.

From the previous section, the researchers concluded that the observations from the Senior Circle were similar to those expected from similar location seen in Table 1. However, for Newton Observatory, the null hypothesis was rejected, thus concluding that maybe the relationship between the observations in this location and other close locations is more complicated. Thus, more research on the amount of light pollution is needed in order to understand the implications of light pollution on Allegheny College's campus. Although the light pollution on campus is below the standards from campus, there is still light impacting the environment and community.

The relationship between light pollution and Allegheny's campus may be complicated to answer without more research because there are many factors that have not been addressed yet. These factors include the impact of light pollution from the city of Meadville and neighboring communities. Based off of our earlier calculations, comparing Senior Circle to Newton Observatory, these locations experience equal amounts of light pollution, however they are not

both equal to the average expected light pollution. Because of these contradictory results, there is the potential that different places on campus experience different amounts of light pollution, during different times. In order to have a better understanding of what places are impacted the most by light pollution, more SQM measurements should be taken at locations mentioned by students in the surveys, such as the Gator Quad, Robertson Athletic Complex, and Brooks Walk. In addition, measurements off campus should be recorded in areas surrounding Allegheny's campus.

Although the SQM does a great job with giving an estimate of light pollution in the sky, this procedure has a few issues that should be corrected. Initially, the results from the SQM may be slightly off because of the cloud and snow cover. For example, during the measurements for this experiment, the sky was completely full of clouds. However for a majority of the data found on the Unihedron database, the sky was clear or almost clear. As a result, we may be seeing numbers that might be slightly lower than they should be in reality. More research on light pollution and albedo with clouds and snow should be considered, and future researchers should consider taking observations year-round. In addition, this procedure cannot tell us exactly how much energy is being lost into the external environment. Because of this, we are not able to accurately calculate how much money Allegheny can save. As a result, we will have a hard time convincing the administration of Allegheny College that addressing light pollution is a worthwhile investment. Finally, it is suggested that an entire energy audit should be assessed for outdoor lighting fixtures to understand the impact that light pollution could have on energy savings.

Does Light Pollution impact the lives of students on campus?

One of the main questions I asked was whether or not students were aware of the environmental problem of light pollution and if it was impacting their daily lives. Of the 301 respondents, approximately 266, or 88.4%, responded that they have heard of this problem. Of these 266, approximately 180, or 67.7%, responded that they have experienced light pollution on Allegheny College's campus. The vast majority of students who responded to this survey were able to identify light pollution on campus, and even provide locations of where they experienced it.

In the survey question, “Experiencing a night sky that is not impacted by light pollution is important to me”, 71.8% of students agreed or strongly agreed with this statement. As a result, even though Allegheny is below the recommendations for outdoor lighting according to the Lux Meter measurements, students prioritize experiencing a dark sky in their daily lives, thus it should be a priority for the school as well.

It was hypothesized that light pollution was impacting the lives of students on campus by impacting night time activities such as stargazing, sports, recreation and amateur astronomy. Looking at the data from the surveys, we can see that there is a relationship between light pollution and the lives of students on campus. However, it may not be as simple as light pollution impacting their outdoor activities such as stargazing. Based off responses to the statement, “Night lighting interrupts my extracurricular activities”, 42.5% of respondents agreed or strongly agreed with that statement. In the question, it was proposed examples of “extracurricular activities” as Stargazing, Night Walks, Meditation, and Sleeping. For this question, we can see that the results are not unanimous. A large portion of respondents disagreed or were neutral to this statement. One explanation we can conclude is that although the light pollution we see on campus may be impacting lives of students, potentially it may be impacting it in a way not described by the survey. Another interpretation is that students find that light pollution may not impact their daily activities at all. This could mean that light pollution may simply be just a minor inconvenience, if any at all. Consequently, it is recommended that more research should be done on the direct relationship between light pollution and the lives of students on campus.

Students also appear to value night time safety on campus. 87.7% of respondents agreed or strongly agreed with the statement “Outdoor lights are necessary for safety”. If Allegheny decided to address light pollution on its campus, safety and security would have to be prioritized as well. It is has been reported that outdoor lighting and safety are closely related (Gallaway, 2010). Students may be sensitive to these considerations because of a violent event that happened on Allegheny College’s campus in December of 2019. Because of this, there may have been an inflation of the concern about safety on campus, and Allegheny will prioritize safety with upcoming renovations. According to April Thompson, Allegheny’s Dean of Students, this could include increasing outdoor lighting (Thompson, 2019). Because of these factors, it would

be recommended to send out another survey directed at students in a similar manner after more time has passed from any safety incidents.

Although Allegheny will be investing in increasing outdoor safety, there are ways that Allegheny can address both safety and light pollution concerns. Allegheny could choose to update the outdoor lighting fixtures, and begin utilizing outdoor lighting fixtures that are energy efficient, downwardly directed, and function at a lower intensity. More example of how Allegheny can update the current light fixtures will be located in Table 2.

Further, many of the locations of light pollution suggested by the students were different from the locations those focused on in this paper. The most frequently reported locations were located outside of buildings such as residence halls (Brooks Hall, Delta Tau Delta fraternity house etc.), the Pelletier Library, and the Campus Center. These locations tend to have lights that do not turn off, that bleed through the windows at night.

Although we can see that the students on campus generally agree with the fact that light pollution impacts their lives, our understanding of how it directly impacts students is still unknown. More research regarding how light pollution impacts the lives of students on campus must be done. Future studies might attempt to address concerns such as:

- Does light pollution impact the sleep of students?
- How does light pollution directly impact the lives of students on campus?
- Is there a relationship between students' mental health and light pollution?

In conclusion, Allegheny does an adequate job with minimizing the impacts of light pollution on campus. However, since Allegheny is known for its sustainability and its commitment to the student body, there is more that it can do to be more efficient and smart about light pollution on campus. The first thing that Allegheny can do is it replace the current light bulbs with LEDs that are closer to red on the electromagnetic spectrum (wavelength around 600-700 nm). Additionally, Allegheny can replace any floor lights with the Eco- Disks (see Table 2), which are dimmer, less expensive, and waste less energy. Not only this, but Allegheny could also help the students on campus by reducing light pollution around residence halls. Many of the comments on the surveys were students indicating that lights outside of residence halls were interrupting sleeping schedules. In these cases, it is possible for Allegheny to simple redirect the light so that it is not directed in to the students' residence halls.

Future Research: Is it worth it? Outdoor Light Energy Audit

From this paper, it can be concluded that Allegheny has a lot of work to effectively minimize light pollution on campus. In order to improve this procedure, it would be recommended that future researchers collected data on light pollution in locations other than Senior Circle and Newton Observatory. Relevant locations include outside of residences halls, the community surrounding Allegheny's campus, Robertson Athletic Complex, and the Gator Quad. Further, more data should be recorded including the weather, the phase of the moon, and other variable conditions. Also, it is recommended to produce another survey aimed to understand how light pollution impacts the everyday lives of students on campus. In addition, it is necessary to understand how much energy waste is caused by light pollution. A potential idea to continue this project would be to complete a light energy audit of Allegheny College's campus. Specifically, a student or professor could figure out what type of light fixtures and bulbs are currently in place, and calculate the total energy output of the outdoor lights through the following equation.

$$Total\ Daily\ Use = (\#\ of\ fixtures) * (length\ of\ time\ each\ fixture\ in\ hrs) * \left(Wattage\ per\ fixture\ (in \frac{W}{hrs})/ 1000\right)$$

In order to determine if the alternatives are worth the splurge, you will need to calculate approximately how much energy it takes to use the current fixtures, and compare that to the cost that the alternative fixtures would cost annually. To calculate the annual cost to run these fixtures you can use the following equation.

$$Total\ Annual\ Energy\ Consumption = (Total\ Daily\ Use) * (365\ days)$$

$$Total\ Annual\ Cost\ for\ Fixtures = (\$0.08\ /\ KWh) * (Total\ Annual\ Energy\ Consumption)$$

To find the return of investment, the annual cost and the purchase cost will need to be compared, and the length of time it will take to save the same amount as the initial cost to buy the new fixture will have to be calculated (Access Fixtures, 2017).

Afterwards, the researcher can calculate the amount of energy it would take to use the alternative fixtures for the same amount of time at the same price and compare that to what Allegheny already has. If the results for the alternative fixtures are above the current calculations, as in the annual energy cost is greater than the current energy costs, then the current fixtures are more energy efficient than the ones that are being proposed in this paper. However, if the results of the alternative energy costs are below the current calculations, the researcher will need to calculate how long it will take Allegheny to earn a return of investment. This will be determined by understanding how much Allegheny will save each year, and how long it will take the yearly savings to offset the cost of installing new fixtures. Examples of fixtures and alternative light sources are provided in the table below.

Table 2 : Example of Alternative light sources

Type of Fixture	Total Cost of Fixture	Total Energy Cost (kWh)	More Info
1.VOLT® Stratum 12" Brass Two-Tier Path & Area Light 	$84.97	LED Voltage:	https://www.voltlighting.com/outdoor-landscape-lighting-12v-path-area-lighting-brass-stratum12/p/BDL-300-12-BBZ
2. Eco Disks 	$9.91	N/A (No Voltage)	https://www.glow.co.uk/eco-disc.html

The fixtures listed above would make great recommendations to replace the current outdoor lighting fixtures. Specifically, the Eco Disk would make a perfect candidate especially for locations such as Senior Circle, Newton Observatory, and the Gator Quad. All of these locations do not have a nighttime demand, and would benefit from any lighting aesthetics. Specifically, the Gator Quad and Senior Circle have upward facing floor lights that mimic the aesthetic of Eco disks. These lights would be a great alternative. Eco disks provide efficient outdoor lighting, which will help students identify pathways, and see around their general surroundings. In addition, eco disks do not require any electricity, so the expenses would be buying the product and maintenance.

Appendices:

Appendix A: Understanding Sky Quality Meter Measurements

mag/arcsec^2	Definition
22	the average brightness of a moonless night sky that's completely free of artificial light pollution
21	rural area in the eastern U.S., with a medium-sized city not far away. It's comparable to the glow of the brightest section of the northern Milky Way, from Cygnus through Perseus
20	outer suburbs of a major metropolis. The summer Milky Way is readily visible but severely washed out.
19	suburb with widely spaced single-family homes. It's a little brighter a remote rural site at the end of nautical twilight, when the Sun is 12° below the horizon.
18	Bright suburb or dark urban neighborhood. It's also a typical zenith skyglow at a rural site when the Moon is full. The Milky Way is invisible, or nearly so.
17	Typical near the center of a major city such as New York or Boston.
13	The zenith skyglow at the end of civil twilight, roughly a half hour after sunset, when the Sun is 6° below the horizon. Venus and Jupiter are easy to see, but bright stars are just beginning to appear.
7	The zenith skyglow at sunrise or sunset.

Appendix B: Raw data from SQM observations

Location	1 (Senior Circle)	2 (Newton)		
A	17.03	16.9	Day 1	2/11/20
B	16.48	15.03	Weather	Cloudy
C	16.67	16.43	Latitude/ Longitude	41°38'50"N, -80° -8'-48"W
D	16.65	16.08		
A	16.01	16.06	Day 2	2/17/20
B	16.01	15.31	Weather	Cloudy
C	16.02	16		
D	15.96	15.78		
A	16.65	16.53	Day 3	2/24/20
B	16.65	14.61	Weather	Cloudy
C	16.6	16.4		
D	16.57	16.59		
mean	16.35375	15.94875		
SD	0.2312826554	0.7945229176		

Appendix C: Standards for urban outdoor lighting

Source

Table 3: Comparison of light level recommendations to measurements.

RECOMMENDATIONS (2000)			MEASUREMENTS (2012)		RECOMMENDATIONS (2011)	
HORIZONTAL	**LUX (LX)**	**FOOT-CANDLES (FC)**	**LUX (LX)**	**FOOT-CANDLES (FC)**	**LUX (LX)**	**FOOT-CANDLES (FC)**
Average	10.00*	1.00*	17.11*	1.59*	7.80*	0.80*
Maximum: Minimum Uniformity Ratio	10:1	10:1	10:1	10:1	10:1	10:1
Average: minimum Uniformity Ratio	4:1 – 10:1	4:1 – 10:1	5:1	5:1	4:1	4:1
VERTICAL						
Average	22.00***	2.20***	24.33**	2.26**	2.6**	0.24**
Maximum: Minimum Uniformity Ratio	NA	NA	8:1	8:1	NA	NA

Illuminance Method – Recommended Values

Road and Pedestrian Conflict Are		Pavement Classification (Minimum maintained Average Values)			Uniformity Ratio E_{av} /E_{min}	Veiling Luminanc Ratio L_{vma} /L_{av}
Road	**Pedestrian Conflict**	**R1 lux/fc**	**R2 & lux/fc**	**R4 lux/fc**		
Freeway Class A		6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Freeway Class		4.0/0.4	6.0/0.6	5.0/0.5	3.0	0.3
Expressway	High	10.0/1.0	14.0/1.4	13.0/1.3	3.0	0.3
	Medium	8.0/0.8	12.0/1.2	10.0/1.0	3.0	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Majo	High	12.0/1.2	17.0/1.7	15.0/1.5	3.0	0.3
	Medium	9.0/0.9	13.0/1.3	11.0/1.1	3.0	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Collector	High	8.0/0.8	12.0/1.2	10.0/1.0	4.0	0.4
	Medium	6.0/0.6	9.0/0.9	8.0/0.8	4.0	0.4
	Low	4.0/0.4	6.0/0.6	5.0/0.5	4.0	0.4
Local	High	6.0/0.6	9.0/0.9	8.0/0.8	6.0	0.4
	Medium	5.0/0.5	7.0/0.7	6.0/0.6	6.0	0.4
	Low	3.0/0.3	4.0/0.4	4.0/0.4	6.0	0.4

Appendix D: Survey Sample

Light Pollution Survey

This survey contains questions about light pollution impacts on campus. Light pollution is defined by nighttime artificial illumination that is scattered through the atmosphere. This type of pollution can have implications on human health, psychology, astronomical studies, and ecology. Please answer these questions about your relationship with light pollution to the best of your ability.

This survey is entirely voluntary and anonymous. No personally-identifying information will be collected. You will not be penalized if you choose not to participate in the survey, or if you choose to discontinue the survey at any time after the beginning.

The survey will take approximately 2 minutes for you to complete. You should only take the survey once. Taking this survey will not expose you to any risks, and the information you provide will be used for a senior comprehension project.

1. Are you 18 years or older

Yes

No

2. Have you ever heard of the environmental issue of light pollution? *

Yes

No

3. Have you experienced light pollution on campus?

Yes

No

Unsure

4. Where have you experienced light pollution on campus? (Check all that apply) *

Robertson Athletic Complex
Senior Circle
Gator Quad
Outside of Residence Halls
Outside of Academic/ Administrative Buildings
None of the Above
Other:

5. Please respond to the prompt based on how strongly you agree or disagree with the statement: Night lighting interrupts my extracurricular activities (Example: Stargazing, Night Walks, Meditation, Sleeping etc.) *

Strongly disagree
Disagree
Neutral
Agree
Strongly agree

6. Please respond to the prompt based on how strongly you agree or disagree with the statement: Outdoor lights are necessary for safety

Strongly disagree
Disagree
Neutral
Agree
Strongly Agree

7. Please respond to the prompt based on how strongly you agree or disagree with the statement: Experiencing a night sky that is not impacted by light pollution is important to me.

Strongly Disagree
Disagree

Neutral

Agree

Strongly Agree

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