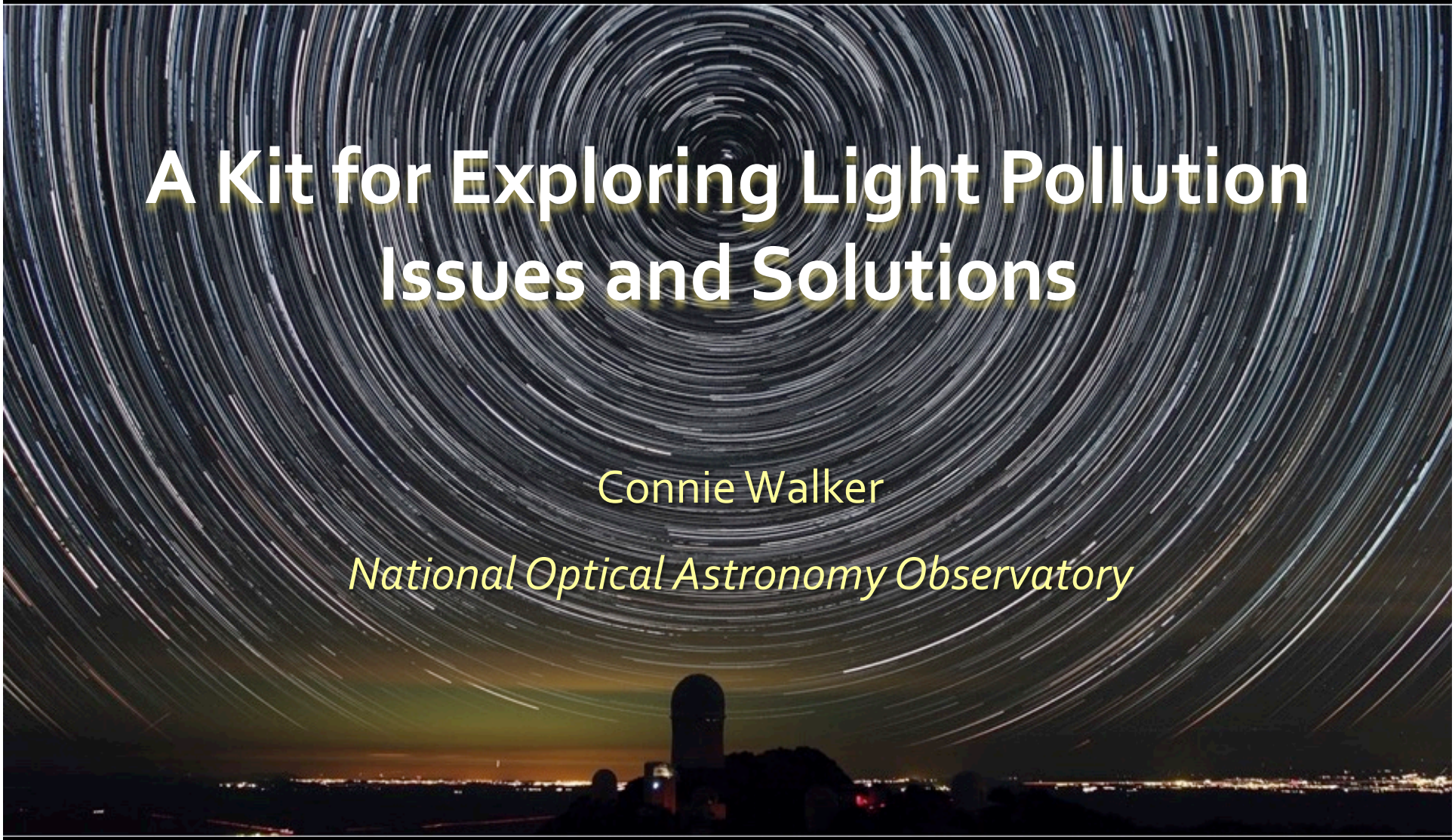


A Kit for Exploring Light Pollution Issues and Solutions

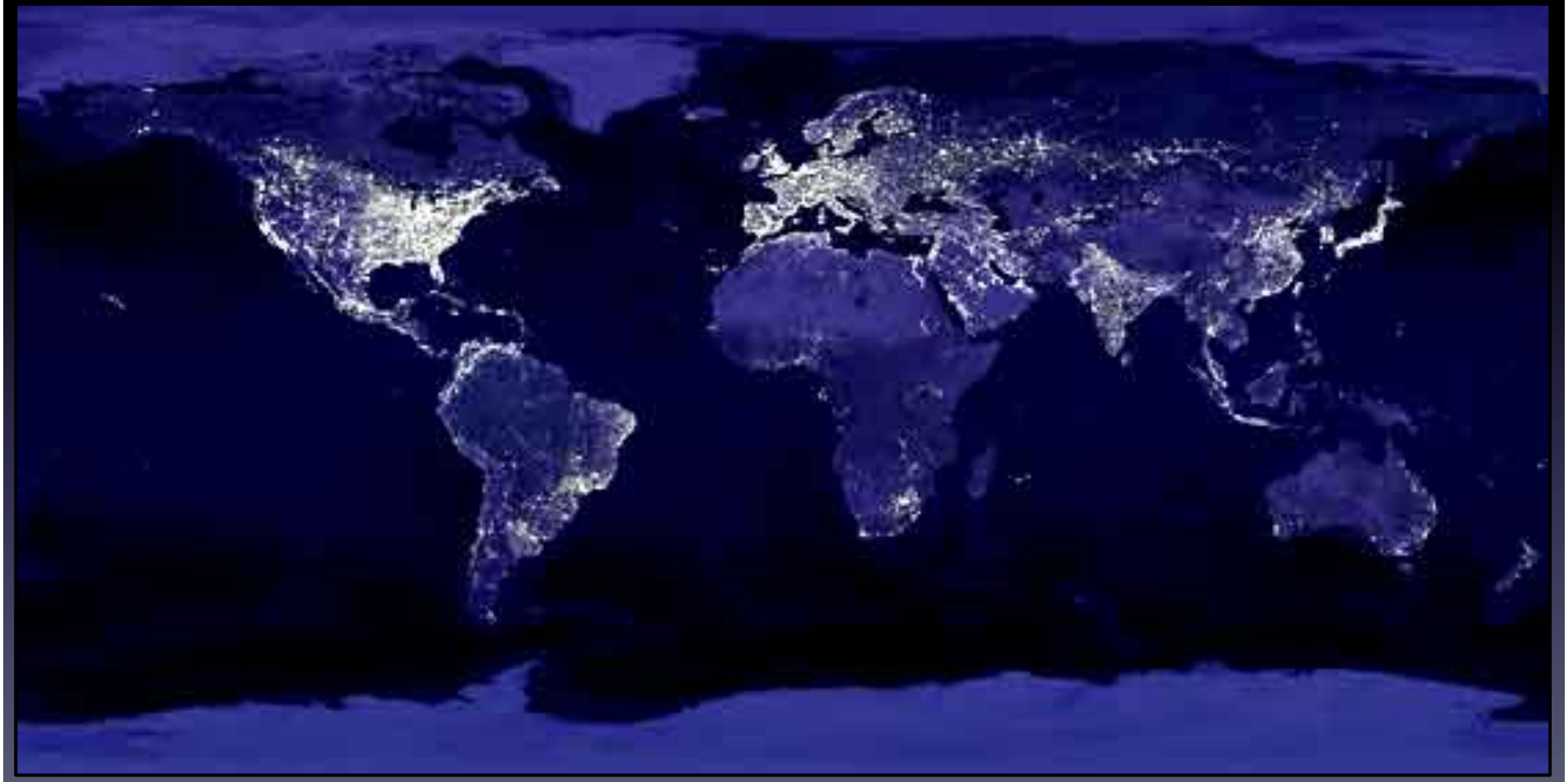
Connie Walker

National Optical Astronomy Observatory

Imagine Everyone Enjoying This Sky

London – 1880
first street lights

Light pollution is a global issue with local solutions…



Light Pollution affects…

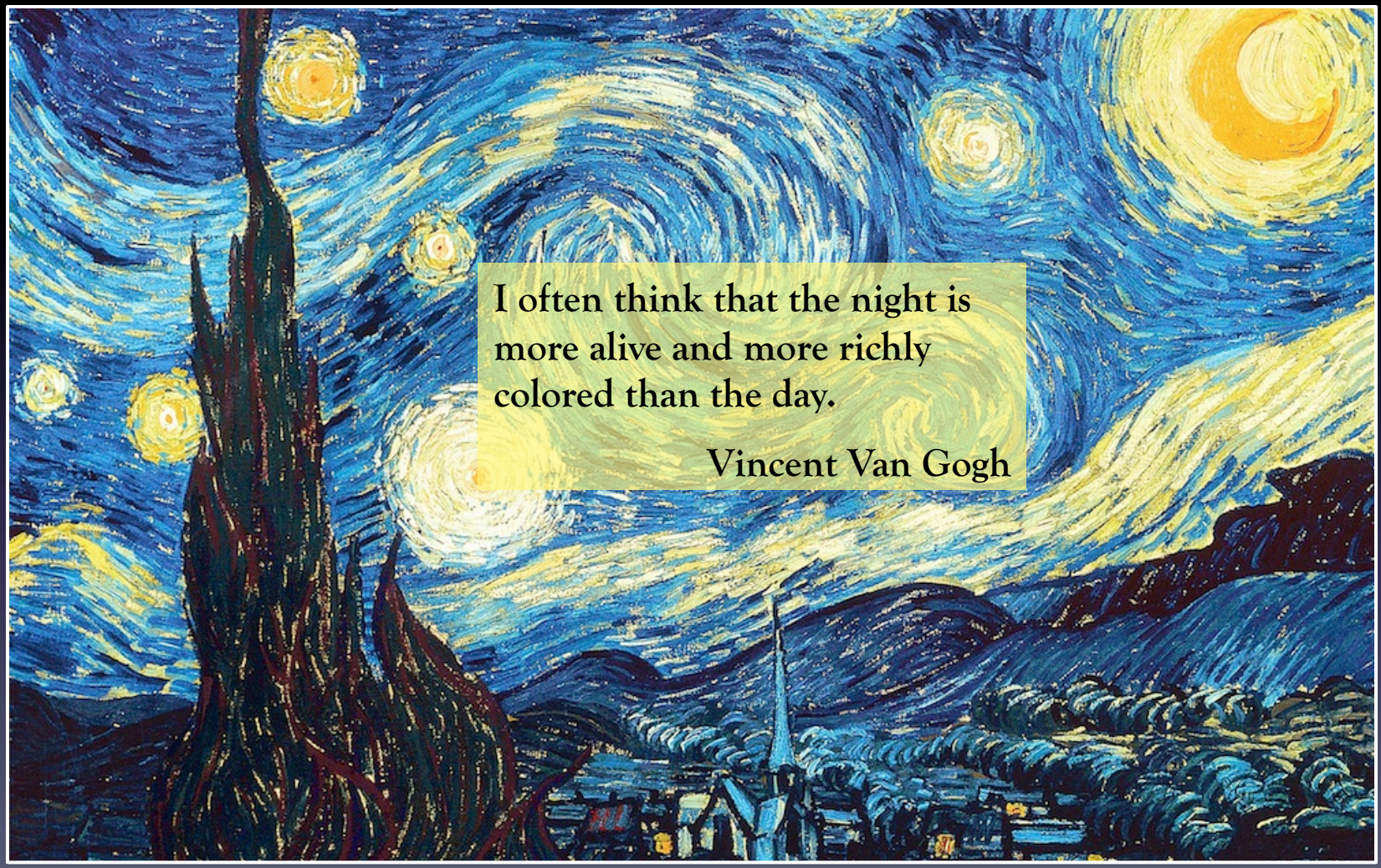
Astronomical Research

Energy, Safety & Cost

Human Health

Wildlife

Cultural Heritage



Quality Lighting Teaching Kit

- One of 5 International Year of Light "Cosmic Light" projects funded by the International Astronomical Union.
- Produced by the National Optical Astronomy Observatory's Education and Public Outreach group for IYL2015
  - Dark Skies Rangers, Dark Skies Africa, Dark Skies Yuma
- Launched in December. To be used in schools, afterschool programs, museums and national parks.
- Designed around problem-based learning scenarios.
- Adaptable to age group, venue, time allotment, etc.

Quality Lighting Teaching Kit

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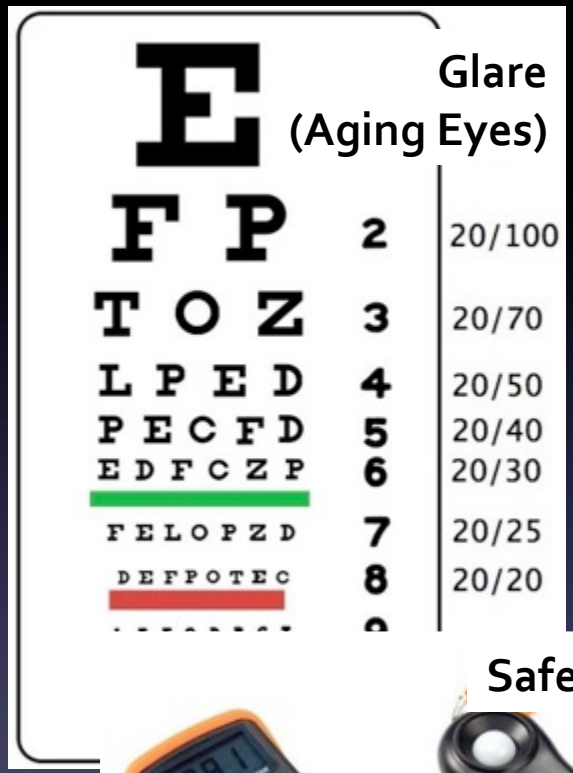
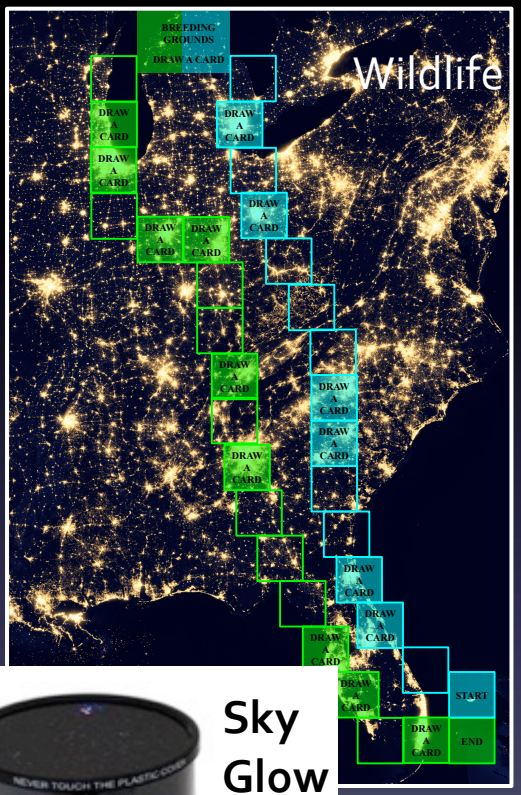
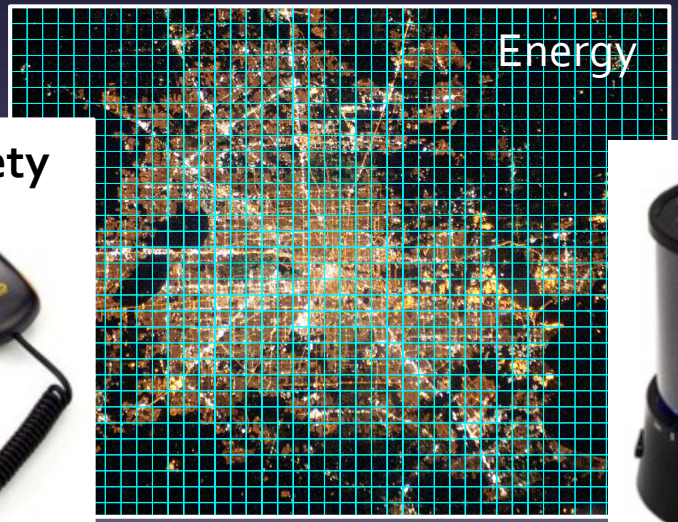
Quality Lighting Teaching Kit







Overall Approach

- Teacher = Mayor of the city.
- Citizens have complaints about lighting.
- Students get into task groups to solve six issues.
- Context with respect to the City of the Future.

Issues Raised by Citizens

Energy

Dear Mayor,
I am a small business owner, and I rent a space in a shopping center. Our electricity bill is astronomical! We do everything we can to conserve energy at our store. Can't you make a rule to turn off the lights after a certain time or something?
Sincerely,
Bill Payne

Dear Mayor,
I think our city is wasting a huge amount of energy and money! Could we make the brightest lights dimmer? Do we need to light all of streets all night long? Some locations (especially intersections) have too many lights! We need to do more to reduce our carbon footprint.
Sincerely,
I.M. Green

Glare

Dear Mayor,
I have lived in this city for my entire life, but not with all your new-fangled lights on the streets. It is very hard to see while driving at night. They shine right in my eyes, which is very painful! The city should do something about this!
Sincerely,
Iris Auld

Dear Mayor,
The lights from the sports field are very bright and shine all over the place, especially into my eyes while driving by them at night. I have had close calls with other drivers. Can't they just keep the lights on the field and not on the street?
Sincerely,
Bea Wright

Animals

Dear Mayor,
I am a representative with the city's Audubon Society, and I love birds. Our city is on a migration path, and every year hundreds of birds are killed due to collisions with brightly lit buildings. What can we do about this?
Sincerely,
Birdy Knight

Dear Mayor,
When I was growing up here, you could hear the sound of frogs on the lake every night, but since the new marina went in with its bright nighttime lights, I don't hear them anymore. Can anything be done to fix this?
Sincerely,
Marina Bay

Safety

DEAR MAYOR,
WHY ARE OUR STREETS AND SIDEWALKS SO BRIGHT AT NIGHT? I'M WORRIED WHEN I'M OUT WALKING MY DOG THAT SOMEONE MIGHT JUMP OUT FROM THE SHADOWS AT ME AND I FEEL UNSAFE.
SINCERELY,
TERRI FIDE

Dear Mayor,
I like to walk the hike n' bike trail along the river at night, but the lights are really bright and make shadows near the river bank. I'm afraid that if I step out of the way of people on bikes that I could fall.
Sincerely,
Beau Coup-deLumiere

Light Trespass

Dear Mayor,
Every night my neighbor's porch light and a streetlight on our street shine right into my children's bedroom windows. We have curtains, but the light still comes in. It is hard for them to fall asleep with the light shining in their faces. I'm sick and tired of this light trespassing onto my property! What can the city do?
Sincerely,
Kurt Tan

Dear Mayor,
I live behind a major shopping center in town. The parking lot & building lights stay on all night. The bright lights shines into mine and my neighbors' homes at all hours of the night. Why can't the light be turned off after hours?
Sincerely,
N. Som Nia

Night Sky

Dear Mayor,
My daughter and I love looking at planets with our telescope at home. When I was growing up here, you could see an infinite number of stars, but now I can only show my daughter just a few of the brightest ones. The inspiration that was once there is now gone! There must be some way to keep the skies dark for future generations.
Sincerely,
Sol and Skye Noir

Dear Mayor,
I'm a member of the city's amateur astronomy club. We hold weekly star parties in the park, as has been the tradition for many decades. But now we can't see the stars in the Milky Way Galaxy anymore! We're going to lose this tradition! Help!
Sincerely,
Luna Crater

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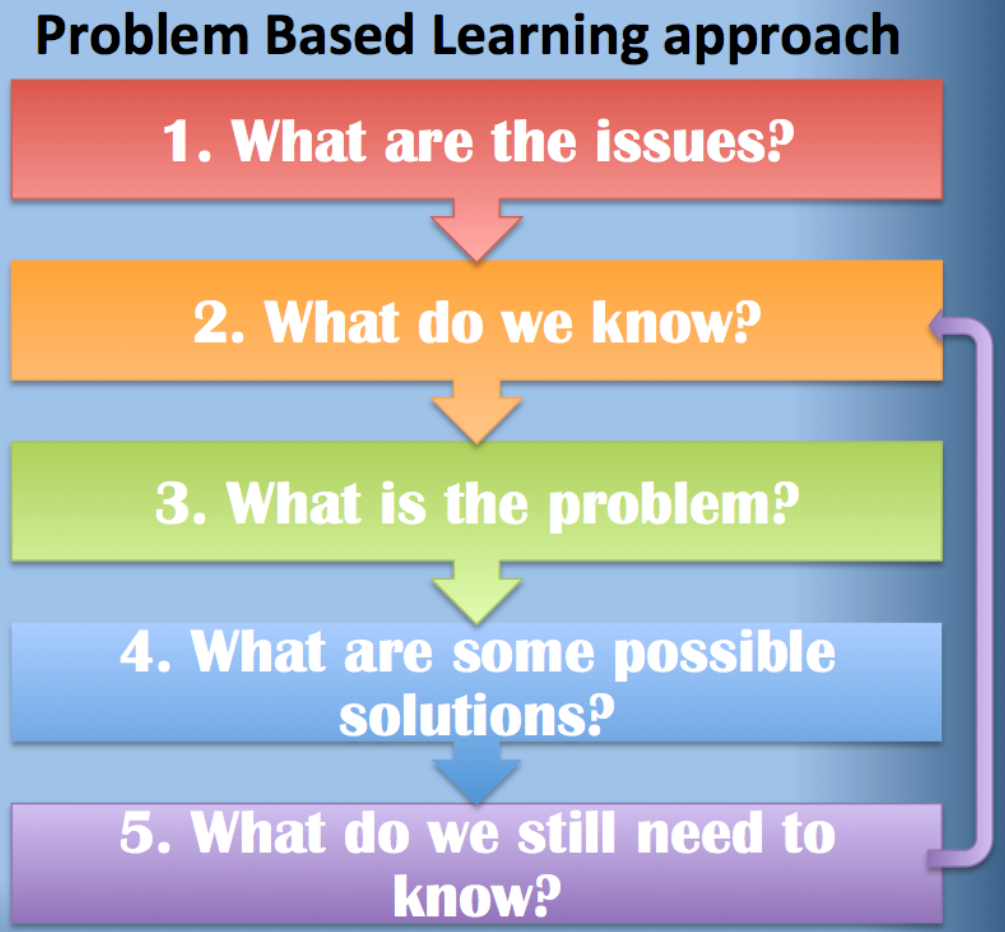
Overall Approach, cont'd

- First, background is provided through 6 posters.
- Students read the poster, search with key words, and do an activity with the kit supplies.
- Then students address the issues using "PBL"
- Presentations made to the Mayor.



Light Pollution and Safety

Safety

- Does more light mean more safety? Not necessarily!
- While we need light to see at night, bad lighting can be just as unsafe as no lighting at all!
- Glare from lights makes it harder to see, especially while driving.
- Look at the two sets of images to the right. Can you see the person in the left pictures? What about in the right pictures? What's different about the lights in each scene?

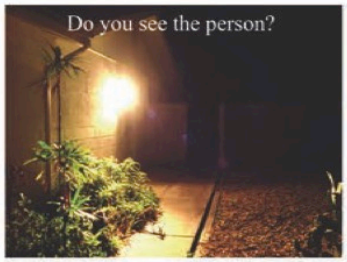
Crime

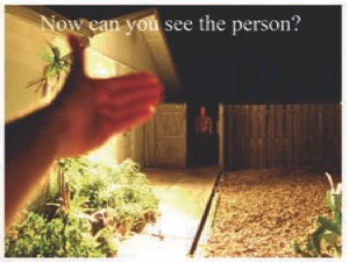
- Lights which are glaring or overly bright can be easy hiding spots for burglars.
- Lights which are poorly shielded or glaring can create shadows where people can hide.
- People feel more safe in the light. But criminals can hide in the excessive light or shadow.
- Roughly *half* of all crimes are committed during the day time. Outdoor lighting by itself does not keep you or your property safer than little or no light.

Public Lighting Standards

- The table below lists minimum recommended lux or brightness levels for outdoor lights in different areas. The bigger the number, the brighter the area. Intersections of streets are lit about 2X the rest of the street.
- The Mayor will have a more detailed table of brightness levels for indoor lighting as well as for the outdoors.

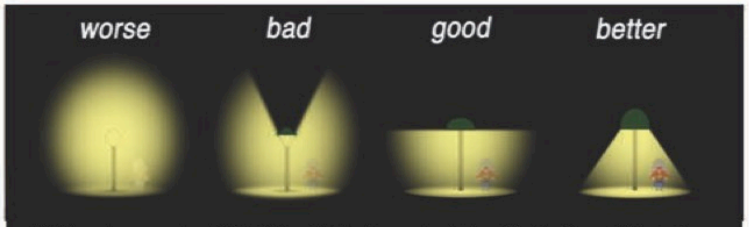
Area	Brightness Level (lux)
Suburban Street	6
Highway	8
Major Street	11
Parks, Schools, Buildings	11
Parking Lot	22
Sports Stadium	500





Lighting Responsibly

- Responsible, safe lights should light up the ground without being glaring.
- Glare is caused by an overly bright, exposed bulb.
- Lights should be task-oriented, meaning that they have a specific purpose.
- How much light is actually needed? What is the minimum amount of light needed to see? Does the light cause shadows?



Different amounts of shielding lights (none to fully shielded) put light where you need it and sometimes where you don't. When can you see the person?

Key Ideas

- Light pollution and safety
- Light pollution and crime
- Public lighting lux levels

Now Try This!

- Take out the lux meter and read the instructions on how to use this brightness measuring device.
- To calibrate the lux meter, keep the cap on the sensor and turn the lux meter on. What should the reading be? Calibrate before each set of measurements. Always make multiple measurements per location. Record readings after each measurement, noting all pertinent details.
- You will be exploring ranges of lighting levels for different locations and deciding what minimum light levels are needed to accomplish tasks in those areas and still stay safe.
- Take the lux meter cap off to measure the brightness of a regularly lit classroom. Then make the classroom as dark as you can and repeat the measurement. Then measure the book light turned on in the dark room. Always put the meter at the point of interest. For example, in a dark classroom, the lux meter may be on the desk next to the book light where a student is reading.
- Take measurements in the school's restroom, library and main office to see how they compare with standard light levels of 200, 300 and 500 lux, respectively. Take measurements outside in sunlight (1000 lux).
- If you can visit a home, a restaurant, a supermarket, a hospital or places in the list on the left with the lux meter, take a few measurements per area.
- If not, perhaps the Mayor can gather extra lights and with a dark classroom, simulate the lighting levels corresponding to one or more areas listed in a table the Mayor will provide. For example, an operating room at a hospital is between 750 and 1500 lux.
- Compare your measurements with the Mayor's provided list of light levels and the list to the left. Determine what numbers or range of numbers a lux meter should read to have enough light to see and stay safe, but not to over-light each area. How might you design a light to do this? Do all parts of the city need to be lit the same amount?
- Create a powerpoint, a video, or a poster in which the issues, problem(s), and your resulting recommendations are presented to the Mayor.

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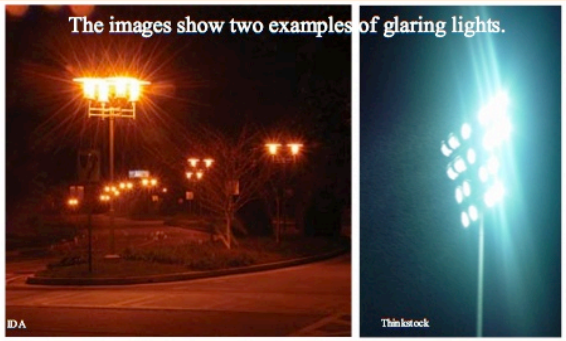
Light Pollution and Glare

Glare

- Glare is a visual sensation caused by an overly bright, exposed bulb, meaning that you can see the light bulb itself.
- Glare can be disabling or simply uncomfortable. (See section on *Disability vs Discomfort Glare*.)
- Older people are usually more sensitive to glare due to the aging characteristics of the eye. (See section on *Aging Eyes*.)
- Because glare causes pain or discomfort, it can be very unsafe. When a light is glaring to the eye, it makes it very hard to see, especially while driving.
- Have you ever been blinded by car headlights? That's glare!
- Glare affects everyone in some way.

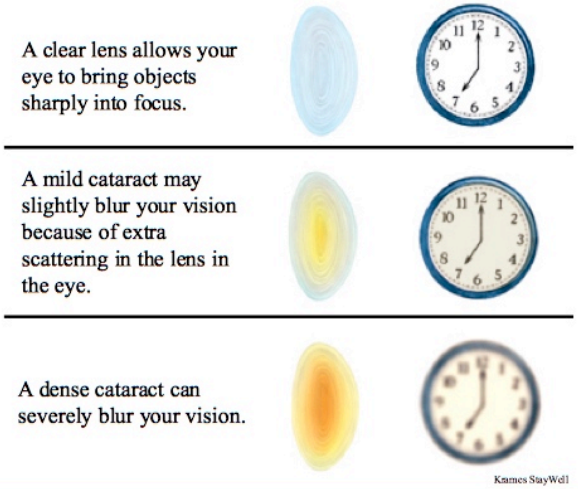
Shielding and Dimming

- Glare is reduced when the light bulb is not exposed.
- Lights should be task-oriented, meaning they light what they were designed to light.
- When a shielded fixture orients all the light downward, often bright light is no longer needed and the wattage can be lowered.



Aging Eyes

- Glare can severely affect people with aging eyes.
- Many people of all ages wear glasses. Glare from lights can scatter off dust, dirt, scratches, or smudges on the lenses making the effects of glare worse.
- As some people age, they lose some control of the muscle that changes the size of the pupil when light levels change. This means that if a light is very bright, the pupil will stay open wider in older people and more light will enter the eye. This can be very painful.
- Cataracts cloud the lens inside the eye. Symptoms include blurriness, lights appearing brighter, poor color perception, and difficulty seeing at nighttime. Advanced cataracts can be corrected with surgery. The clouding causes more light to scatter inside the eye. Glaring lights can cause pain and more blurring!
- Nearly everyone over the age of 60 has pre-cataracts, which can cause yellowed or blurry vision.



Disability vs Discomfort Glare

- Disability glare is the reduction in vision caused by intense light sources in the field of view, while discomfort glare is the sensation of annoyance or even pain induced by overly bright sources.
- Disability glare degrades your vision by decreasing your ability to see contrasts and color perception. The loss of vision is caused by stray light being scattered within the eye.
- With discomfort glare, the light can be so painfully bright, that is causes you to have to look away from the light.

Now Try This!

- Post the eye chart at eye level on a wall. We're going to use this to explore how glare affects people with and without aging eyes.
- Read the smallest line you can at a distance of 6 meters (20 feet) from the chart. Record the line number you read. For students with glasses, try to read the smallest line you can with and without your glasses. For perfect vision, you should be able to read line 8.
- Then try again with 1 layer of the fuzzy transparency immediately in front of your eyes; repeat with 2 layers, 3 layers, and then 4 layers. Each time, record the line numbers you read. The layers of transparency will simulate different severities of cataracts.
- Now make the room as dark as you can. Using the large flashlight in your box, fully illuminate the eye chart (so you can still see it). Repeat the second and third steps.
- Keeping the room lights off, have one person in the group stand near the eye chart pointing the Maglite in your eyes. Repeat the second and third steps under these conditions.
- What are the problems? Using your experience here and some background research online, formulate recommendations to solve the problems and to address the complaints from the *Issues Poster* for this case scenario.
- Create a powerpoint, a video, or a poster in which the issues, problem(s), and your resulting recommendations are presented to the Mayor.

Key Ideas

- Glare
- Aging eyes
- Cataracts
- Glare and safety
- Discomfort glare
- Disability glare

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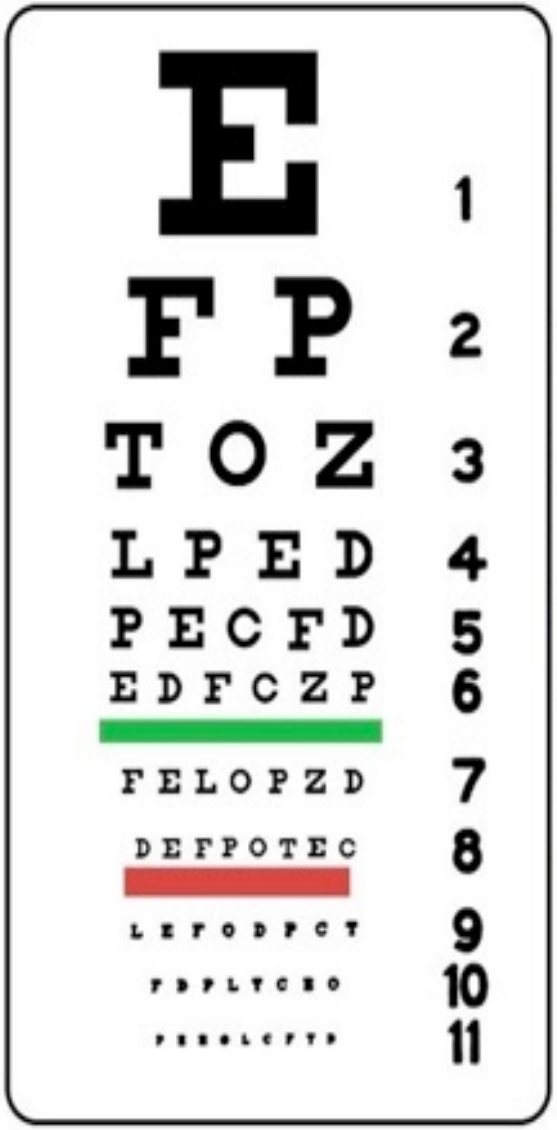

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Light Pollution and Light Trespass

Light Trespass

- Light trespass is when light goes somewhere it is unwanted and unneeded, such as into a bedroom window at night.
- As you may have experienced, it can be hard to fall asleep or stay asleep with light shining into your room.

Blue Light at Night

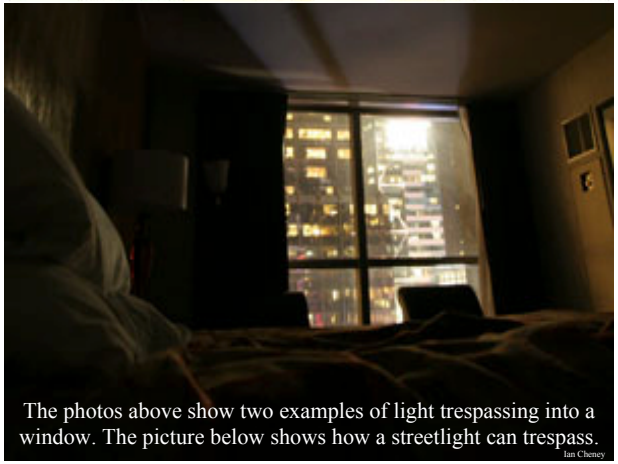
- Most white lights contain all the colors of the rainbow and a lot of blue.
- Blue light at night can have negative effects on people who are frequently exposed to it.
- Because blue light waves are the right size to bounce off particles in our atmosphere, it easily scatters in our atmosphere and thereby contributes to a lot of light pollution.
- While you sleep, a chemical called melatonin is produced. Melatonin helps regulate many functions in our body. Any light at night will decrease melatonin production, but blue light suppresses production more than other colors of light.

Sleep Cycles

- Humans have a biological clock that follows the 24 hour cycle of day and night called the circadian rhythm.
- Exposure to light at night can disrupt this cycle, such as light from a streetlight coming in the window or looking at computer, tablet, or phone screens before bed.
- This can cause fatigue and insomnia (the inability to sleep at night) as well as other sleep disorders and health issues.

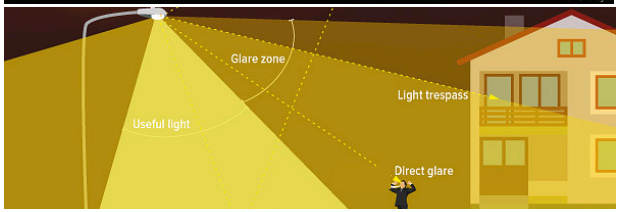
Key Ideas

- Light trespass
- Circadian rhythm
- Blue light at night
- Light shielding
- Light pollution and health
- Task-oriented lights



The photos above show two examples of light trespassing into a window. The picture below shows how a streetlight can trespass.

Ian Cheney



Lighting Responsibly

- Making sure lights are task-oriented is key to reducing light trespass. Task-oriented means the light has a specific job. How can the light be directed only where it needs to be?
- How might the height of the pole or the spacing between poles affect light trespass?

Now Try This!

- You will have a scene that includes a street, a house, a streetlight (represented by a Maglite or book light), and one figurine of a person. The person should be in the house, laying by the window as if they are sleeping.
- Place the house near the street but in the grass. Remove the cap on the Maglite, and place it on the bottom of the Maglite to be used as its base. Carefully put the ping pong ball over the bulb. Place the Maglite across the street from the house. What are your observations? Where is the light going? Where is the light not going? Where should the light be going? Try moving the Maglite to different locations. Record your observations. To log your observations, you may want to make a table. Repeat this step using the black cap provided in your box.
- Repeat the above step with the book light. Also try changing the angle of the top of the book light from 45 degrees to horizontal.
- Try to recreate the problems presented in the *Issues Poster* using each of the lights. What are the problems? Can you make the light go into the window?
- Think of ways to solve the issues and problems you came up with. What might your solutions look like? Can you draw a picture of it? You should also make a case for why this is an important issue. Generalize this beyond the *Issues Poster*. What is the purpose of the streetlight? What are the consequences (both positive and negative) of your solution(s)?
- Create a powerpoint, a video, or a poster in which the issues, problem(s), and your resulting recommendations are presented to the Mayor.

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- Task-oriented lights

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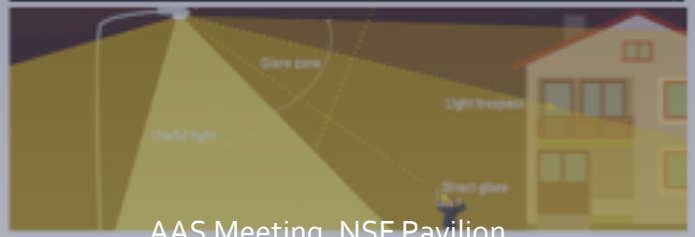

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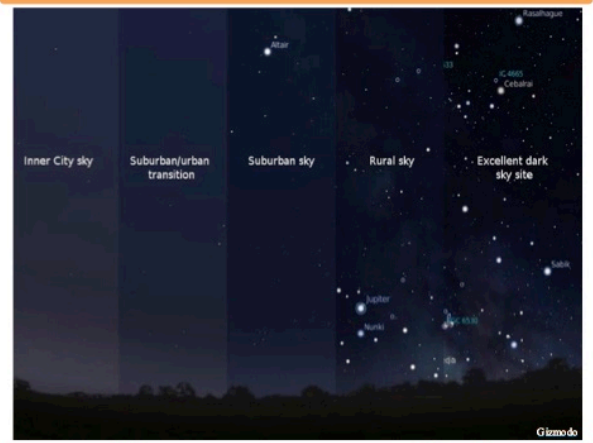
- Think of ways to solve the issues and problems you came up with. What might your solutions look like? Can you draw a picture of it? You should also make a case for why this is an important issue. Generalize this beyond the *Issues Poster*. What is the purpose of the streetlight? What are the consequences (both positive and negative) of your solution(s)?
- Create a powerpoint, a video, or a poster in which the issues, problem(s), and your resulting recommendations are presented to the Mayor.

Light Pollution and the Night Sky

Sky Glow

- Sky glow is when lights from a city shine up into the night sky. This light scatters off particles in the air causing a glowing haze over the city and washing out the stars.
- Millions of people have never seen the Milky Way in the night sky due to sky glow.
- Sky glow affects astronomers trying to study objects in outer space.
- Sky glow is evidence of wasted light, energy & resources.

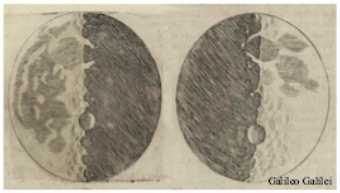


Wasted Light

- Light going up into the night sky that creates sky glow is light that is wasted and not used where needed on the ground.
- Roughly 30% of the light used outside is wasted in this way.

Key Ideas

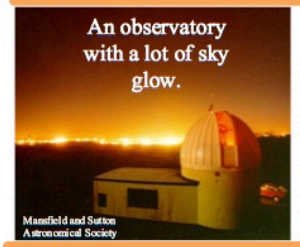
- Sky glow
- Night sky heritage
- Globe at Night
- Light pollution and astronomy



The night sky inspires science and art.

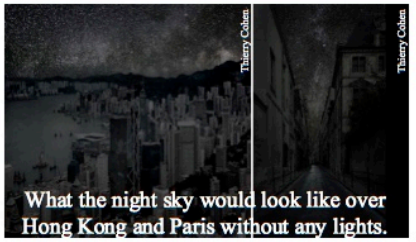
Heritage

- A clear view of the night sky has been crucial for navigation for centuries.
- It has inspired art, music, literature, science, philosophy, and human curiosity in general.
- How can we preserve this piece of our cultural heritage for future generations?
- International Dark Sky Places are places dedicated to preserving a dark night sky. (See darksky.org/idsp/).



Observatories & Astronomers

- Most astronomers need a dark sky to be able to study all of the faint objects in outer space.
- If a city produces too much sky glow, astronomers can no longer see faint objects, and the observatory can become usable.
- Different types of light can affect the data astronomers collect at observatories. Lights which only emit a single color (like low pressure sodium lights) are better because astronomers can remove that one color from their data. However, white light contains all the colors of the rainbow; removing all colors would leave no data for the astronomers to use.



Now Try This!

- Keep the star projector in its box with the lid open and place a piece of black construction paper under the box. Make the room as dark as you can, and turn the star projector on by pressing the "LED" button.
- Hold a piece of white paper above the star projector to see the entire circle. Try count the number of stars you see on the paper. Record this number along with setting conditions. You may want to make a table to record this information.
- Next, take the cap off the Maglite to be used as its base, put on the ping pong ball, and place it next to the star projector. Estimate what percent of the stars are left (10%? 50%? 75%?). Record this number along with setting conditions and your observations. Repeat this step using the cap in your box to cover the light.
- Repeat the above step using the book light rather than the Maglite, both with and without the black cap on top. Also try adjusting the angle of the book light.
- Write down recommendations you have for how to maximize the number of stars while having enough light for people to still see. How can the lights be changed? Is there a better option than the lights presented? What might your solution look like? Using materials provided by the Mayor, construct a new shield to go on the lights. Be sure to test it using the star projector. What percent of stars are left with your new shield? Generalize this beyond the issues in the *Issues Poster*. What are the consequences (both positive and negative) of your solution(s)?
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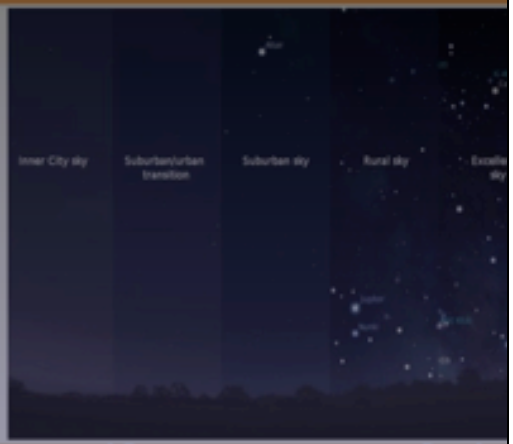

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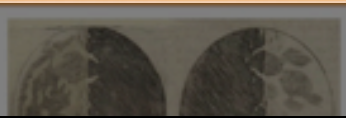

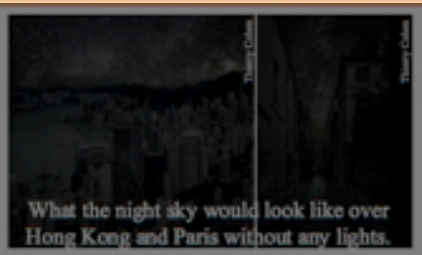

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Light Pollution and Animals

Sea Turtles

- After sea turtles hatch, they make their way to the ocean, as shown in the picture to the right.
- Normally, sea turtles hatch at night when most predators are asleep.
- They use the light of the moon and stars reflecting off the ocean to find their way.
- If there are bright lights near the beach, the sea turtles go the wrong direction and never make it to the ocean.

Birds

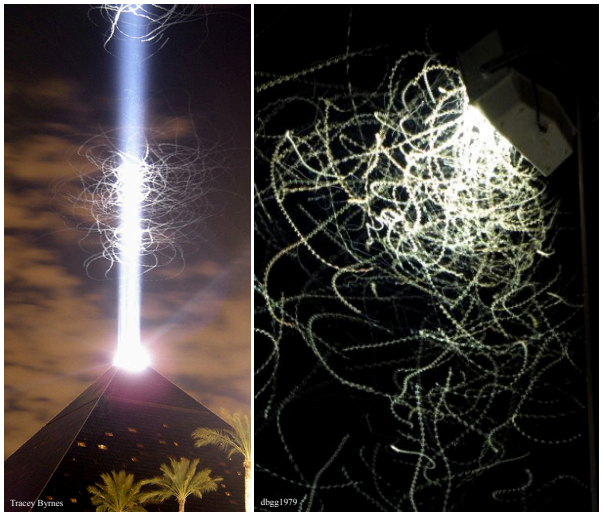
- Migrating birds can become confused by bright lights.
- Birds will circle around the light, become exhausted, and collapse or die.
- The photograph on the bottom left shows birds circling around a very bright column of light.
- Birds can also crash into bright buildings, causing injury or death.
- It is estimated that between 100 million - 1 billion birds die from striking buildings every year in North America alone.

Insects

- Insects see primarily blue and purple light. Bright white lights usually have a lot of blue light.
- Insects will circle around lights, making them easy prey for predators.
- The bottom right photo shows insects flying around an outdoor light.

Key Ideas

- Sea turtles and light
- Bird strike lights
- Animal navigation
- Wildlife and light pollution



Newly hatched sea turtles (top) and insects (bottom right) are attracted to light. Birds and bats are attracted to light from the Luxor in Las Vegas, Nevada, USA (bottom left).

Other Animals

- Light pollution affects the habitats and habits of other animals including bats, amphibians, and marine animals.
- Some animals affected by light pollution, like sea turtles, are already endangered species.

Sleep Cycles

- Animals have an intrinsic biological clock that allows them to tell time.
- When animals are exposed to lights at night, this biological clock is disrupted and they become fatigued and disoriented.
- This can also disrupt migration and mating patterns.

Now Try This!

- You have a game board, game pieces (buttons), game cards, a die, and game instructions. In this game, you are a Kirtland's Warbler, a type of bird, migrating north from the Bahamas to the breeding grounds in the Great Lakes region of the United States and back again. These birds mostly fly at nighttime.
- Read the game instructions for information on how to play the game.
- After you've played the game, discuss what happened. What are the problems? How do these related to the issues raised in the *Issues Poster*?
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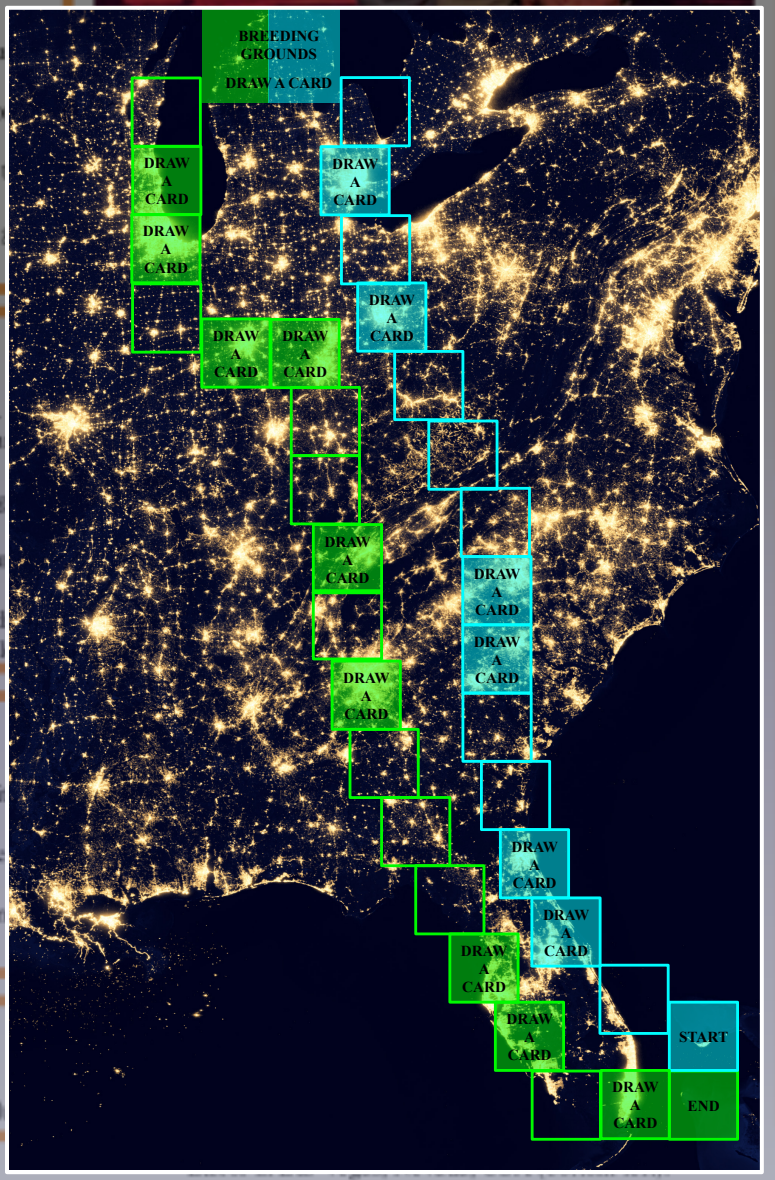

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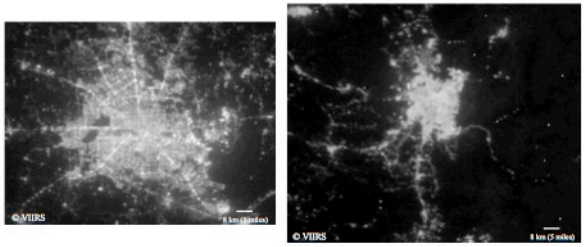
Light Pollution and Energy

Energy Waste

- All the light you see in the images is wasted. About 30% of all outdoor light is being wasted by shining upward.
- Energy is a precious resource. Most electricity is produced by burning fossil fuels, which are non-renewable and are quickly being depleted.
- How can we keep the light from going up, and instead, keep it down where we need it?

Cost

- Lighting accounts for 11% of the total energy usage in the United States by all sectors (residential, commercial, industrial, and transportation).
- In 2012, each person in the United States spent over $3000 on energy usage.
- The United States accounts for 18% of the world's energy consumption.
- An estimated $3.3 billion is spent on wasted energy in the United States.
- How can individuals and families reduce their energy costs? How can cities and countries reduce costs?



The pictures above show the urban area of Houston, Texas, USA (left) and the province of Santiago, Chile at night from space. The populations of urban Houston and the province of Santiago each have roughly 4.9 million people, but the area of the province of Santiago is twice as large as urban Houston. The brightnesses are on the same scale. How do these brightnesses compare?

Carbon Footprint

- A carbon footprint is the amount of greenhouse gases emitted due to burning fossil fuels. Greenhouse gases (like carbon dioxide) contribute to climate change by trapping heat that would otherwise escape into space.
- Most electricity in the United States is produced by burning fossil fuels (39% by coal, 27% by natural gas, and 1% by petroleum). Fossil fuels are the fossilized remains of plants that lived hundreds of millions of years ago.
- For each kilowatt-hour of energy produced, 0.84 kg (1.85 lbs) of greenhouse gases are released into the atmosphere.
- An estimated 875 million trees would have to be planted every year to offset all the carbon dioxide released.

This image shows Europe at night from space. Each bright dot is a city; these cities are between the sizes of Houston and Santiago. All of the light in this picture is being wasted.

Efficient Bulbs

- One way to reduce energy waste, cost, and carbon footprint is to use energy efficient light bulbs.
- Efficiency is an output over an input, or how much light you get out for the amount of energy you put in.
- See the "Types of Lights" handout for more information.

Shielding

- Another way to help reduce energy cost is to cover the light bulb, so that the light does not go up (where it is wasted). Concentrating all light downward (where needed) allows for the bulb's wattage to be reduced.
- Lights should be task-oriented, designed for a specific purpose while seeing the light on the ground, but not the bulb.

Now Try This!

- Examine the International Space Station (ISS) aerial photograph of Houston, Texas, United States found in your group's folder. Notice the grid of squares superimposed on the city; there are 1,344 squares total. Each square of the grid is 3 km (1.8 miles) on a side.
- There are three different colors of lights on the map: white, yellow, and brown. The white lights are usually in lines following the roads, the yellow lights are blobs of densely packed lights, and the brown lights are spread all over.
- Count the number of squares of each color, marking the squares with a different colored marker or pencil. You'll probably want to make a key. When counting squares, count any square that is more than half lit. If there is more than one type of light in one square, pick whichever light takes up more of the square. Do not double count squares!
- The white lights are 250 Watt (W) Metal Halide lights, the yellow are 150 W High Pressure Sodium lights, and the brown are 250 W High Pressure Sodium lights.
- Refer to the "Energy Calculation Mat – First Side" to see how to calculate energy, cost, and carbon footprint from these lights for one night, as well as the light being wasted in one night. Discuss your results with your group.
- Using the "Types of Lights" handout, reduce the energy, cost, and carbon footprint by changing the types of lights, number of lights, length of time the lights are on, etc. Then calculate the energy, cost and carbon footprint for the improved situation using the "Energy Calculation Mat – Second Side".
- Based on your results, make some general recommendations about the changes you made. You should also consider whether there are some places or cases in the city where their general recommendations may not work. What would work better in those cases?
- Create a powerpoint, a video, or a poster in which the case study and your resulting recommendations are presented to the Mayor.

Key Ideas

- Energy efficient light bulbs
- Carbon footprint
- Energy for lighting
- Energy waste

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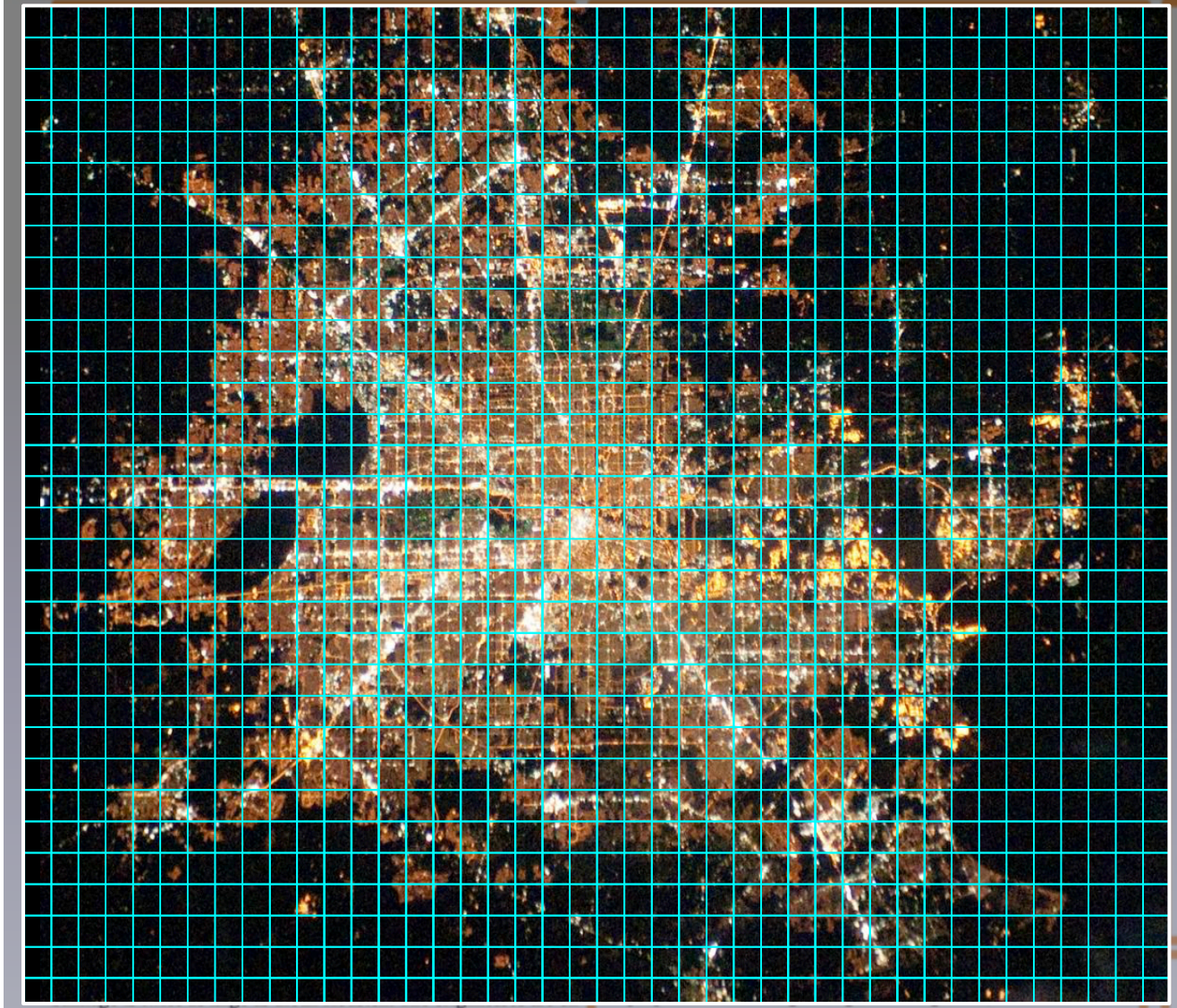
Light Pollution and Energy



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Energy Calculation Mat, Side 1

Energy Calculation Mat

First Side

Start here

You will use the information on this page and the results from counting the squares on the city grid to determine the energy, cost, and carbon footprint of the lights from this city.

Bulb Type 1: Metal Halide

Wattage of the bulbs: 250

Lumens of light: 22,000

Number of squares:

Bulb Type 2: High Pressure Sodium

Wattage of the bulbs: 250

Lumens of light: 24,000

Number of squares:

Bulb Type 3: High Pressure Sodium

Wattage of the bulbs: 150

Lumens of light: 16,000

Number of squares:

For all bulbs:

Cost of electricity per kilowatt-hour: $0.08

This will depend on how your region produces electricity. For Houston, the average is $0.08 per kWh.

All bulbs will be turned on for **11 hours** per night.

There are **2,000,000 bulbs** in this city.

The total number of squares on the grid is **1,344**.

Note: In this document, a comma (,) is used for the thousands (or millions) place in large numbers and a period (.) is used for the decimal place. In many countries, this is reversed. Don't let this confuse you!

Number of squares of Bulb Type 1:

Number of squares of Bulb Type 2:

Number of squares of Bulb Type 3:

+

Number of Lit Squares:

Totals

Finally, let's look at our city as a whole and calculate the total amount of energy, money, and greenhouse gases *wasted* each night.

	Energy Wasted (kWh):	Cost Wasted ($):	Carbon Footprint Wasted (kg):
Bulb Type 1:			
Bulb Type 2:			
Bulb Type 3:			
+			
Grand Total:			

Bulb Type 1

Use the numbers in the colors above to complete the next section of this worksheet. Repeat these steps for each type of bulb.

For this first set of calculations we will use **Bulb Type #1**. First we will find the efficacy of each bulb. The efficacy is the ratio of lumens to watts. The efficacy is related to the efficiency, but they are not the same thing. A larger efficacy means the bulb is more efficient. Which of the bulbs has the highest efficacy?

Step 1: Lumens of Type 1 ÷ Wattage of Type 1 = Efficacy of Type 1

We want to determine what percent of all lights are of Type 1. To do this, we'll take the number of squares of Type 1 and divide it by the total number of lit squares.

Step 2: Number of squares of Type 1 ÷ Number of Lit Squares = Percent of lights that are Type 1

Now we want to determine how many bulbs of Type 1 are in the city. To do this, we'll take the percent of Type 1 and multiple it by the total number of lights in the city (2,000,000).

Step 3: Percent of lights that are Type 1 × 2,000,000 = Number of bulbs of Type 1 in the city

In this next step, we will find the energy used in one night. Electric utility companies measure energy in a unit called watts. For example, if you have a 100-watt bulb and the light is on for 11 hours it uses 100W*11 hours or 1,100Wh). To calculate the amount of energy used, the wattage (in watts) of the bulbs is multiplied by the estimated number the bulbs.

Step 4: Wattage of Type 1 × 11 hours in one night = Energy used in one night by one bulb of Type 1

Now let's take a closer look at energy, cost, and carbon footprint.

Because of how quickly watt-hours add up, the term kilowatt-hour is used to represent 1000 watt-hours. You can convert the number of watt-hours to kilowatt-hours by dividing the number of watt-hours (or energy) by 1000. This is the amount of energy used in one night.

Step 5: Energy used in one night by one bulb of Type 1 ÷ 1000 = Kilowatt-hours used in one night for one bulb of Type 1

An important part of light pollution is the enormous cost of that is required to keep the lights turned on. Electric utility companies charge for electricity by the kilowatt-hour (kWh). Next we will calculate how much it costs to light up one bulb of Type 1 for one night.

Step 6: Kilowatt-hours used in one night for one bulb of Type 1 × $0.08 (Cost per kilowatt-hour) = Amount spent on one bulb of Type 1 in one night

Electricity is most commonly produced from coal, natural gas, or nuclear power. When chemicals are burned, greenhouse gases are emitted that contribute to air pollution and climate change. The final important aspect of light pollution is the amount of greenhouse gases that are emitted during the production of electricity. Greenhouse gases are measured by the mass of the carbon dioxide gas. The amount of greenhouse gases produced depends on the type of fuel used to produce electricity. Because that's hard to know exactly, we're going to use an average of 0.84 kg per kilowatt-hour. To calculate how much greenhouse gas is produced, you need to multiply the kilowatt-hours used in one night by 0.84kg/kWh.

Step 7: Kilowatt-hours used in one night for one bulb of Type 1 × 0.84 $\frac{kg}{kWh}$ = Amount of greenhouse gas produced by one bulb of Type 1 in one night

Now let's determine how much energy, cost, and carbon footprint is used for the entire city in one night. To do this, we'll multiply the results from the previous page for one bulb by the total number of bulbs we calculated in Step 3.

Step 8: Kilowatt-hours used in one night for one bulb of Type 1 × Number of bulbs of Type 1 in the city = Kilowatt-hours used in one night for all bulbs of Type 1

Step 9: Amount spent in one night for one bulb of Type 1 × Number of bulbs of Type 1 in the city = Amount spent in one night for all bulbs of Type 1

Step 10: Amount of greenhouse gas produced in one night for one bulb of Type 1 × Number of bulbs of Type 1 in the city = Amount of greenhouse gas produced in one night for all bulbs of Type 1

Now let's determine how much light is being *wasted* by shining up into the sky. Roughly 30% of the light used is wasted. We'll multiply the results from the above steps by 30% or 0.3 to determine the wasted light.

Step 11: Kilowatt-hours used in one night for one bulb of Type 1 × 0.3 = Kilowatt-hours *wasted* in one night for one bulb of Type 1

Step 12: Amount spent in one night for one bulb of Type 1 × 0.3 = Amount *wasted* in one night for one bulb of Type 1

Step 13: Amount of greenhouse gas produced in one night for all bulbs of Type 1 × 0.3 = Amount of greenhouse gas *wasted* in one night for all bulbs of Type 1

Congrats! You did it!

Bulb Type 2

Now let's repeat the steps for Bulb Type 2.

Step 1: Lumens of Type 2 ÷ Wattage of Type 2 = Efficacy of Type 2

Step 2: Number of squares of Type 2 ÷ Number of Lit Squares = Percent of lights that are Type 2

Step 3: Percent of lights that are Type 2 × 2,000,000 = Number of bulbs of Type 2 in the city

Step 4: Wattage of Type 2 × 11 hours in one night = Energy used in one night by one bulb of Type 2

Step 5: Energy used in one night by one bulb of Type 2 ÷ 1000 = Kilowatt-hours used in one night for one bulb of Type 2

Step 6: Kilowatt-hours used in one night for one bulb of Type 2 × $0.08 (Cost per kilowatt-hour) = Amount spent on one bulb of Type 2 in one night

Step 7: Kilowatt-hours used in one night for one bulb of Type 2 × 0.84 $\frac{kg}{kWh}$ = Amount of greenhouse gas produced by one bulb of Type 2 in one night

Step 8: Kilowatt-hours used in one night for one bulb of Type 2 × Number of bulbs of Type 2 in the city = Kilowatt-hours used in one night for all bulbs of Type 2

Step 9: Amount spent in one night for one bulb of Type 2 × Number of Bulbs of Type 2 in the city = Amount spent in one night for all bulbs of Type 2

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Step 13: Amount of greenhouse gas produced in one night for all bulbs of Type 2 × 0.3 = Amount of greenhouse gas *wasted* in one night for all bulbs of Type 2

Bulb Type 3

Now let's repeat the steps for Bulb Type 3.

Step 1: Lumens of Type 3 ÷ Wattage of Type 3 = Efficacy of Type 3

Step 2: Number of squares of Type 3 ÷ Number of Lit Squares = Percent of lights that are Type 3

Step 3: Percent of lights that are Type 3 × 2,000,000 = Number of bulbs of Type 3 in the city

Step 4: Wattage of Type 3 × 11 hours in one night = Energy used in one night by one bulb of Type 3

Step 5: Energy used in one night by one bulb of Type 3 ÷ 1000 = Kilowatt-hours used in one night for one bulb of Type 3

Step 6: Kilowatt-hours used in one night for one bulb of Type 3 × $0.08 (Cost per kilowatt-hour) = Amount spent on one bulb of Type 3 in one night

Step 7: Kilowatt-hours used in one night for one bulb of Type 3 × 0.84 $\frac{kg}{kWh}$ = Amount of greenhouse gas produced by one bulb of Type 3 in one night

Step 8: Kilowatt-hours used in one night for one bulb of Type 3 × Number of bulbs of Type 3 in the city = Kilowatt-hours used in one night for all bulbs of Type 3

Step 9: Amount spent in one night for one bulb of Type 3 × Number of bulbs of Type 3 in the city = Amount spent in one night for all bulbs of Type 3

Step 10: Amount of greenhouse gas produced in one night for one bulb of Type 3 × Number of bulbs of Type 3 in the city = Amount of greenhouse gas produced in one night for all bulbs of Type 3

Step 11: Kilowatt-hours used in one night for one bulb of Type 3 × 0.3 = Kilowatt-hours *wasted* in one night for one bulb of Type 3

Step 12: Amount spent in one night for one bulb of Type 3 × 0.3 = Amount *wasted* in one night for one bulb of Type 3

Step 13: Amount of greenhouse gas produced in one night for all bulbs of Type 3 × 0.3 = Amount of greenhouse gas *wasted* in one night for all bulbs of Type 3

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Energy Calculation Mat, Side 2

Energy Calculation Mat

Second Side

Start here

You will use the information on this page and the results from counting the squares on the city grid to determine the energy, cost, and carbon footprint of the lights from this city.

Bulb Type 1:_____

Wattage of the bulbs:

Lumens of light:

Number of squares:

For all bulbs:
Cost of electricity per kilowatt-hour:

$0.08

This will depend on how your region produces electricity. For Houston, the average is $0.08 per kWh.

There are **2,000,000 bulbs** in this city.

The total number of squares on the grid is **1,344**.

Note: In this document, a comma (,) is used for the thousands (or millions) place in large numbers and a period (.) is used for the decimal place. In many countries, this is reversed. Don't let this confuse you!

Bulb Type 2:_____

Wattage of the bulbs:

Lumens of light:

Number of squares:

Bulb Type 3:_____

Wattage of the bulbs:

Lumens of light:

Number of squares:

Number of squares of Bulb Type 1

Number of squares of Bulb Type 2

Number of squares of Bulb Type 3

Number of Lit Squares

+

Totals

Finally, let's look at our city as a whole and calculate the total amount of energy, money, and greenhouse gases *wasted* each night.

	Energy Wasted (kWh):	Cost Wasted ($):	Carbon Footprint Wasted (kg):
Bulb Type 1:			
Bulb Type 2:			
Bulb Type 3:			
Grand Total:			

Bulb Type 1

Use the numbers in the colors above to complete the next section of this worksheet. Repeat these steps for each type of bulb.

For this first set of calculations we will use **Bulb Type #1**. First we will find the efficacy of each bulb. The efficacy is the ratio of lumens to watts. The efficacy is related to the efficiency, but they are not the same thing. A larger efficacy means the bulb is more efficient. Which of the bulbs has the highest efficacy?

Step 1: Lumens of Type 1 ÷ Wattage of Type 1 = Efficacy of Type 1

We want to determine what percent of all lights are of Type 1. To do this, we'll take the number of squares of Type 1 and divide it by the total number of lit squares.

Step 2: Number of squares of Type 1 ÷ Number of Lit Squares = Percent of lights that are Type 1

Now we want to determine how many bulbs of Type 1 are in the city. To do this, we'll take the percent of Type 1 and multiple it by the total number of lights in the city (2,000,000).

Step 3: Percent of lights that are Type 1 × 2,000,000 = Number of bulbs of Type 1 in the city

In this next step, we will find the energy used in one night. Electric utility companies measure energy in a unit called watts. For example, if you have a 100-watt bulb and the light is on for 11 hours it uses 100W*11 hours or 1,100Wh). To calculate the amount of energy used, the wattage (in watts) of the bulbs is multiplied by the estimated number the bulbs.

Step 4: Wattage of Type 1 × Hours turned on in one night = Energy used in one night by one bulb of Type 1

Now let's take a closer look at energy, cost, and carbon footprint.

Because of how quickly watt-hours add up, the term kilowatt-hour is used to represent 1000 watt-hours. You can convert the number of watt-hours to kilowatt-hours by dividing the number of watt-hours (or energy) by 1000. This is the amount of energy used in one night.

Step 5: Energy used in one night by one bulb of Type 1 ÷ 1000 = Kilowatt-hours used in one night for one bulb of Type 1

An important part of light pollution is the enormous cost of that is required to keep the lights turned on. Electric utility companies charge for electricity by the kilowatt-hour (kWh). Next we will calculate how much it costs to light up one bulb of Type 1 for one night.

Step 6: Kilowatt-hours used in one night for one bulb of Type 1 × $0.08 = Amount spent on one bulb of Type 1 in one night

Electricity is most commonly produced from coal, natural gas, or nuclear power. When chemicals are burned, greenhouse gases are emitted that contribute to air pollution and climate change. The final important aspect of light pollution is the amount of greenhouse gases that are emitted during the production of electricity. Greenhouse gases are measured by the mass of the carbon dioxide gas. The amount of greenhouse gases produced depends on the type of fuel used to produce electricity. Because that's hard to know exactly, we're going to use an average of 0.84 kg per kilowatt-hour. To calculate how much greenhouse gas is produced, you need to multiply the kilowatt-hours used in one night by 0.84kg/kWh.

Step 7: Kilowatt-hours used in one night for one bulb of Type 1 × 0.84 $\frac{kg}{kWh}$ = Amount of greenhouse gas produced by one bulb of Type 1 in one night

Now let's determine how much energy, cost, and carbon footprint is used for the entire city in one night. To do this, we'll multiply the results from the previous page for one bulb by the total number of bulbs we calculated in Step 3.

Step 8: Kilowatt-hours used in one night for one bulb of Type 1 × Number of bulbs of Type 1 in the city = Kilowatt-hours used in one night for all bulbs of Type 1

Step 9: Amount spent in one night for one bulb of Type 1 × Number of bulbs of Type 1 in the city = Amount spent in one night for all bulbs of Type 1

Step 10: Amount of greenhouse gas produced in one night for one bulb of Type 1 × Number of bulbs of Type 1 in the city = Amount of greenhouse gas produced in one night for all bulbs of Type 1

Now let's determine how much light is being *wasted* by shining up into the sky. Roughly 30% of the light used is wasted. We'll multiply the results from the above steps by 30% or 0.3 to determine the wasted light.

Step 11: Kilowatt-hours used in one night for all bulbs of Type 1 × 0.3 = Kilowatt-hours **wasted** in one night for all bulbs of Type 1

Step 12: Amount spent in one night for all bulbs of Type 1 × 0.3 = Amount **wasted** in one night for all bulbs of Type 1

Step 13: Amount of greenhouse gas produced in one night for all bulbs of Type 1 × 0.3 = Amount of greenhouse gas **wasted** in one night for all bulbs of Type 1

Savings

Finally, let's see how much energy, cost, and carbon footprint we saved by the changes we made!

	Energy Wasted (kWh):	Cost Wasted ($):	Carbon Footprint Wasted (kg):
Values from Old Scenario:			
Values from New Scenario:			
Amount Saved:			

Bulb Type 2

Now let's repeat the steps for Bulb Type 2.

Step 1: Lumens of Type 2 ÷ Wattage of Type 2 = Efficacy of Type 2

Step 2: Number of squares of Type 2 ÷ Number of Lit Squares = Percent of lights that are Type 2

Step 3: Percent of lights that are Type 2 × 2,000,000 = Number of bulbs of Type 2 in the city

Step 4: Wattage of Type 2 × Hours turned on in one night = Energy used in one night by one bulb of Type 2

Step 5: Energy used in one night by one bulb of Type 2 ÷ 1000 = Kilowatt-hours used in one night for one bulb of Type 2

Step 6: Kilowatt-hours used in one night for one bulb of Type 2 × $0.08 = Amount spent on one bulb of Type 2 in one night

Step 7: Kilowatt-hours used in one night for one bulb of Type 2 × 0.84 $\frac{kg}{kWh}$ = Amount of greenhouse gas produced by one bulb of Type 2 in one night

Step 8: Kilowatt-hours used in one night for one bulb of Type 2 × Number of bulbs of Type 2 in the city = Kilowatt-hours used in one night for all bulbs of Type 2

Step 9: Amount spent in one night for one bulb of Type 2 × Number of bulbs of Type 2 in the city = Amount spent in one night for all bulbs of Type 2

Step 10: Amount of greenhouse gas produced in one night for one bulb of Type 2 × Number of bulbs of Type 2 in the city = Amount of greenhouse gas produced in one night for all bulbs of Type 2

Step 11: Kilowatt-hours used in one night for all bulbs of Type 2 × 0.3 = Kilowatt-hours **wasted** in one night for all bulbs of Type 2

Step 12: Amount spent in one night for all bulbs of Type 2 × 0.3 = Amount **wasted** in one night for all bulbs of Type 2

Step 13: Amount of greenhouse gas produced in one night for all bulbs of Type 2 × 0.3 = Amount of greenhouse gas **wasted** in one night for all bulbs of Type 2

Bulb Type 3

Now let's repeat the steps for Bulb Type 3.

Step 1: Lumens of Type 3 ÷ Wattage of Type 3 = Efficacy of Type 3

Step 2: Number of squares of Type 3 ÷ Number of Lit Squares = Percent of lights that are Type 3

Step 3: Percent of lights that are Type 3 × 2,000,000 = Number of bulbs of Type 3 in the city

Step 4: Wattage of Type 3 × Hours turned on in one night = Energy used in one night by one bulb of Type 3

Step 5: Energy used in one night by one bulb of Type 3 ÷ 1000 = Kilowatt-hours used in one night for one bulb of Type 3

Step 6: Kilowatt-hours used in one night for one bulb of Type 3 × $0.08 = Amount spent on one bulb of Type 3 in one night

Step 7: Kilowatt-hours used in one night for one bulb of Type 3 × 0.84 $\frac{kg}{kWh}$ = Amount of greenhouse gas produced by one bulb of Type 3 in one night

Step 8: Kilowatt-hours used in one night for one bulb of Type 3 × Number of bulbs of Type 3 in the city = Kilowatt-hours used in one night for all bulbs of Type 3

Step 9: Amount spent in one night for one bulb of Type 3 × Number of bulbs of Type 3 in the city = Amount spent in one night for all bulbs of Type 3

Step 10: Amount of greenhouse gas produced in one night for one bulb of Type 3 × Number of bulbs of Type 3 in the city = Amount of greenhouse gas produced in one night for all bulbs of Type 3

Step 11: Kilowatt-hours used in one night for all bulbs of Type 3 × 0.3 = Kilowatt-hours **wasted** in one night for all bulbs of Type 3

Step 12: Amount spent in one night for all bulbs of Type 3 × 0.3 = Amount **wasted** in one night for all bulbs of Type 3

Step 13: Amount of greenhouse gas produced in one night for all bulbs of Type 3 × 0.3 = Amount of greenhouse gas **wasted** in one night for all bulbs of Type 3

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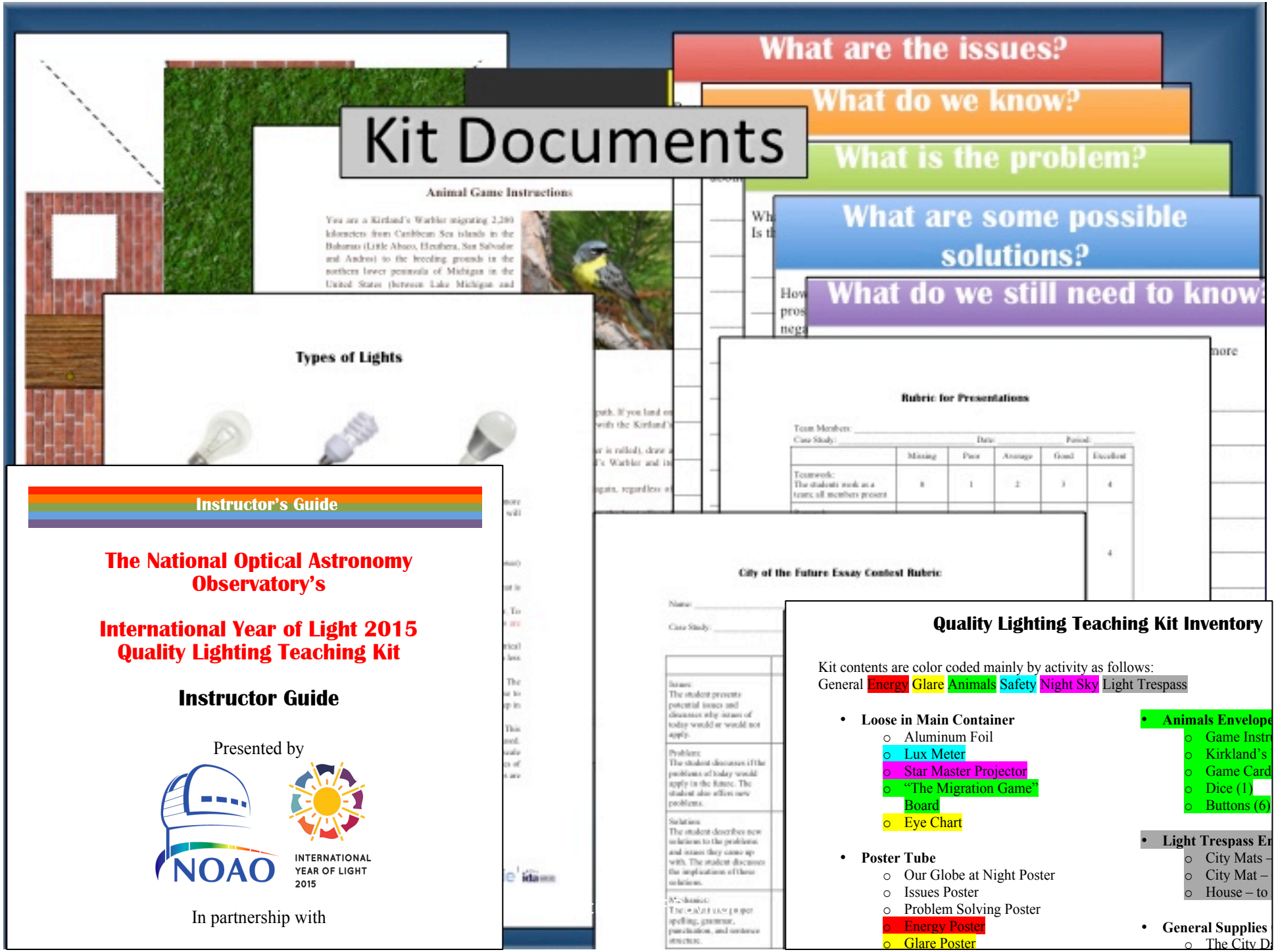
Kit Documents



Instructor's Guide

The National Optical Astronomy Observatory's

International Year of Light 2015
Quality Lighting Teaching Kit

Instructor Guide

Presented by

NOAO

INTERNATIONAL YEAR OF LIGHT 2015

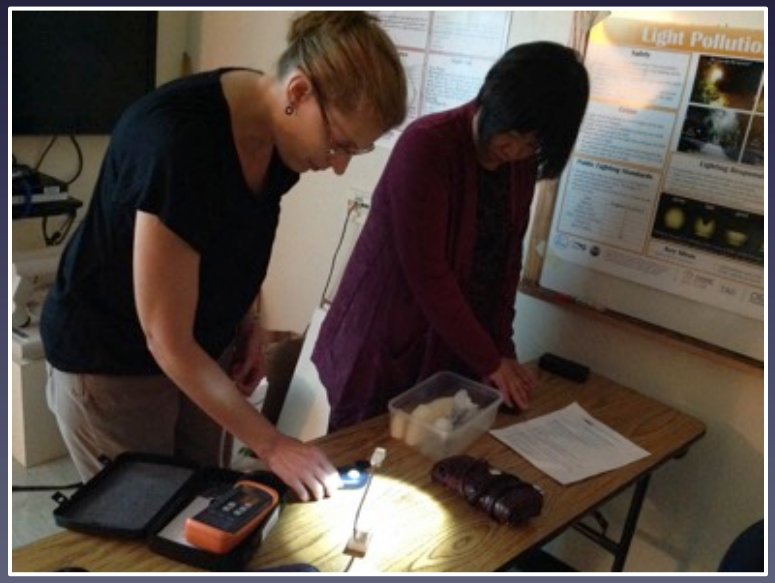
In partnership with

Quality Lighting Teaching Kit Inventory

Kit contents are color coded mainly by activity as follows:
General Energy Glare Animals Safety Night Sky Light Trespass

- **Loose in Main Container**
  - Aluminum Foil
  - Lux Meter
  - Star Master Projector
  - "The Migration Game" Board
  - Eye Chart
- **Poster Tube**
  - Our Globe at Night Poster
  - Issues Poster
  - Problem Solving Poster
  - Energy Poster
  - Glare Poster
- **Animals Envelope**
  - Game Instr
  - Kirkland's
  - Game Card
  - Dice (1)
  - Buttons (6)
- **Light Trespass En**
  - City Mats –
  - City Mat –
  - House – to
- **General Supplies**
  - The City D

5 teacher workshops, a focus group and 15 classroom visits in 2015



Summary

- Through this program, students are presented with real-life issues on light pollution's effects on energy, wildlife, safety, light trespass, glare and the night sky.
- Posters provide background for each issue.
- Activities provide understanding of the issues through experimentation.
- "The City of the Future" poster provides inspiration for students to solve the lighting issue through the Problem-Based Learning.
- Instructional support is provided by the instructor's guide, the video tutorial, the Google+ Hangout, the kit supplies for the activities and other documents.

A hope for the future that…

Many hands will make light work!

Interested in this kit?

- We would like to go for further funding. (Ideas?)
- Interested in future collaborations?
- Interested in receiving (or buying) a kit, email Connie Walker at cwalker@noao.edu using "QLT Kit" in the subject line.
- Websites with our light pollution activities:
  - Quality Lighting Teaching Kit kit (11-14 yrs): www.noao.edu/education/qltkit.php
  - Initial version of the Quality Lighting Teaching Kit (14-18 yrs): www.noao.edu/education/iyl-focus/
  - Dark Skies Rangers activities (8-11 yrs): www.globeatnight.org/dsr/
  - The International Dark-Sky Association: www.darksky.org


Questions?

Globe at Night Citizen-Science

Example: Light Pollution & Safety

- With a lux meter, measure lighting levels in different situations with different lights.
- Determine the lowest level needed to function.

- Compare results with Public Lighting Standards.
- Determine what number a lux meter should read to have enough light to see, but not to over-light an area. How might you design a light to do this? Do all parts of the city need to be lit the same amount?