Lesson Plan

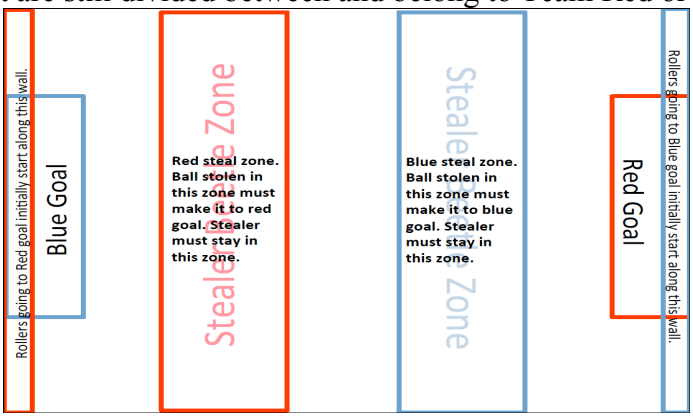
Lesson Title	# Starlight-Steering Scarabs K.D. Denney[1], K. Croxall[1], & W. Schlingman[1] [1]Department of Astronomy, The Ohio State University
Nominal Grade Level	3 – 5 Standard Lesson only; Polarization Supplement (coming soon) suitable for ~6 – 9, though possibly younger with scaffolding and presentation adaptations.
Ohio's New Learning Science Standards Addressed	Standard Lesson: 3(ESS), 3(LS), 4(LS), 5(LS), 5(ESS), 6(ESS), 7(ESS), 7(LS), HS(Bio), HS(ES), HS(PhysGeo) Polarization Supplement (additional): 5(PS), 5(ESS), 7(ESS), HS(PS), HS(physics)
Goals and Objectives for Student Learning	Students will explore the navigation practices of the dung beetle, observations of the sky, and the interactions between the human and dung beetle ecosystems. Main points to be covered include: 1.) Dung beetles use the position of the stars, other celestial objects, and the observed orientation of the Milky Way to navigate their dung ball away from the dung pile. 2.) Dung beetles impact the environment beyond their local ecosystem by tunneling into, carrying away, and eating dung, which, among other things, reduces green house gas emissions that contribute to human-induced climate change. 3.) Humans impact the dung beetle's ecosystem with light pollution, which makes it more difficult for the dung beetles to navigate. 4.) Humans and dung beetles have the potential to have a symbiotic relationship – one that benefits both species – but it is up to humans not to ruin this relationship with light pollution.
Teaching Method(s)	Expository presentation plus kinesthetic learning activity; Polarization Supplement also contains a participatory demonstration
Materials	• Associated PowerPoint Presentation or visit to OSU Planetarium • 8 – 10-inch beach balls • playground sand (used to fill the beach balls; ours weigh 0.5 lb, total weight ball+sand.) • funnel (for getting sand into beach balls) • laser level or some other type of light that can represent Milky Way light and have a definite "orientation" when shown on the ceiling (we have also had success using a flashlight with thin strips of masking tape blocking part of the light from the top of the flashlight, thus leaving several "slits" of light uncovered to give a definite orientation. • Whistle and/or timer, etc. that can sound to periodically halt the game and count down 10 seconds.

	• 2 colors of masking or other tape (to mark stealing zones)
Science Content Background	**Dung Beetles**: Dung beetles, the type of beetle known to the Ancient Egyptians as "scarabs", live on all continents except Antarctica (only because there's not a lot of dung there). These beetles are dependent on **dung** – animal feces or excrement (yes, poop) – for survival. Not only do dung beetles use it for sustenance (yes, they eat it – eww!), some tunnel into it and live in the dung and the soil below it. For most, the dung is also a necessary part of the reproduction process, where a dung ball serves as a **brooding ball** – a safe place for the female dung beetle to lay her eggs. Additionally, the brooding ball serves as a food source for the dung beetle larvae when they hatch. **The Dung Beetle's Need and Method for Navigation**: Some species of dung beetles, like the African rolling dung beetle (scientific name: Family: Scarabaeidae, Genus: Neateuchus, Species: N. proboscideus), find a dung pile, and instead of 'dining in' (living and eating near or under the dung pile), they will 'carry-out or take-away' by rolling a portion of the dung into a ball that they roll away from the dung pile by pushing it backward with their hind legs (see video references below). In order to protect all their hard work from other beetles near the busy dung pile, who may want to steal their dung ball, they roll their dung ball far away from the heap as fast as they can. The most efficient way to do this is in a straight line **radially outward** – like the spokes on a bicycle tire. Dung beetles therefore need a good way to **navigate** – make and carry out a plan for transporting themselves (and their dung ball) somewhere – because they have this survival need to travel in a straight line (so that their food source is not stolen). However, they are also pushing a ball larger than themselves backwards and upside down, so they need something to help them get a sense of which direction is which! Researchers have found that a primary visual cue dung beetles use for navigation is the location of the sun in the sky. However, many species of dung beetles are **nocturnal** – they are awake during the night. Researchers have discovered that one way that dung beetles navigate in a straight line away from the dung pile at night is by using the pattern of the **Milky Way** – the dense (closely-packed) strip of stars and dust that traces a large pattern across the dark night sky. This path in the sky is made up of the billions of stars and cold space dust that form the disk of our own Milky Way spiral galaxy and that give our galaxy its name (ancient Greeks, who had far less light pollution, thought it looked like spilt milk). The dung beetles first figure out the orientation of the Milky Way in the sky and decide which direction they want to take "away" from the dung pile. They then start rolling, periodically stopping to do an "orientation dance" on top of their dung balls, during which they check the sky to make sure they see the Milky

Way to be in the same orientation as it was when they started – so they know they are still going in the same straight line as when they started. They are the one known insect to use the Milky Way for navigation and only one of a few living species known to use visual cues from the night sky for navigation (also humans, seals, and certain types of birds).

The interdependence of the Human and Dung Beetle Ecosystems:
Dung beetles and humans largely have a **symbiotic relationship** – one in which we work together and both species benefit. The dung beetles benefit from human agriculture – in particular raising livestock – because the presence of livestock also means a steady food supply for the dung beetles (everyone poops). In return, the dung beetles provide benefits in numerous ways. Their activity helps with the hydrological properties of the soil, including water infiltration into soil, soil porosity, and reducing surface water runoff, which can lead to erosion. Additionally, dung beetles disperse the dung from the initial pile and/or bury their dung balls. This spreads fertilizer around and below the soil, adding nutrients to the ground for future agricultural use. One of these nutrients is nitrogen, which is very good for the soil, but if dung is left untouched by the dung beetles, this nitrogen is lost to the atmosphere, where it contributes to global warming as a green house gas, nitrous oxide (Note, the amount of nitrous oxide released into the atmosphere may depend on the behavior of the various types of dung beetle; some species reduce the amount released, some increase the amount released). In addition, the tunnels the dung beetles dig into dung piles facilitates the aeration and drying of the dung, which decreases methane production by micro-organisms inside the dung. Methane is another dominant greenhouse gas that contributes to global warming. Because both nitrous oxide and methane production are enhanced by the significant number of grazing animals, such as cattle, used for food production world-wide, this is one example of human-induced contributions to global warming that dung beetles can help mitigate. Finally, by removing dung (and burying it), this leaves a lot less dung lying around. As a result, other organisms, such as flies, that scavenge on dung and that are also responsible for spreading diseases (including typhoid, cholera, dysentery, tuberculosis, salmonella, etc.) do not thrive as they would if there were more dung.

Dung Beetles and Light Pollution:
Because dung beetles are dependent on the Milky Way (or at least many stars) for navigation, their navigation abilities can be severely hindered when they cannot see the stars. While this can happen naturally on cloudy nights, humans can create more problems for the dung beetles from the transmission and reflection of our city lights up into the sky – this **light pollution** can outshine the light from the Milky Way. Do you remember when you have last seen the Milky Way? Were you near or far away from the city? What were the location/conditions like when you did see it? Have you "ever" even seen the Milky Way? Have you seen it in a city? When the dung beetles

	cannot see the Milky Way to navigate, their motion is more like a **random walk** – going in random directions with each step because they have no guide. It would be like being blindfolded and trying to find your way from one side of your classroom to the other, making it around all the desks/tables without being able to see them. Near to the dung pile, there is a lot of competition as beetles try to steal dung balls from each other. When the dung beetles can't get quickly away from the other beetles near the dung pile, it's harder for the beetles to successfully provide food for themselves and their family.
Learning Activities	**Kinesthetic Activity: The Dung Beetle Game** **Motivation**: To gain a better understanding of the obstacles dung beetles must overcome in their day-to-day life, students will play the role of dung beetles trying to roll their dung ball (actually a weighted beach ball) from the dung pile to the safety of their **burrow** – their home. They must not only protect their dung ball from other dung beetles that may want to steal it, but they must "navigate" their way by periodically checking the orientation of a mock Milky Way. **Goal**: To safely navigate your dung ball from "the dung pile" to your burrow across the room. **Procedure**: 1) ~1/3 of beetles (e.g., Team Red) start on one side of the room with their dung balls; ~1/3 of beetles start at the opposite side of the room with their dung balls (e.g., Team Blue), and ~1/3 beetles are "stealer" beetles who start in the "stealing zones" and do not have dung balls start out with, but are still divided between and belong to Team Red or Team Blue.  2) The lights in the room are turned off and the "Milky Way" (laser line or flashlight with slits) is shown on the ceiling. The game begins by the beetles with dung balls completing their **orientation dance** – spinning in a circle three times next to their dung ball and then "orienting" their arms so they point along the same direction as, i.e., parallel to, the Milky Way.

(The stealer beetles don't need to do this).

3) The game begins and students must "crab walk", pushing their dung balls in front of them with only their feet, trying to make it to the other side of the room, while trying to avoid the stealer beetles who want to steal their dung ball. **Note:** the beetles do not "kick" their balls far away and then have to catch up to them (this is a good way for them to get stolen); they keep in contact with their dung balls, pushing only a little bit at a time as quickly as possible.
4) Periodically, a teacher/moderator changes the orientation of the Milky Way and blows the whistle, which signifies that the beetles need to recheck their orientation – do their orientation dance. When the whistle blows, a 10 second timer/count down also starts that freezes the stealer beetles (see below). **Note:** In real life, the Milky Way itself will not change its orientation, but the beetles may have gotten turned around and so must adjust their course because they can't actually "see" their goal destination. In the game, the student beetles can see their destination across the room, so they don't actually need the Milky Way to navigate, but this act of having to stop their rolling and search out and verify the orientation of the Milky Way at least simulates the beetles' real life act of completing a similar exercise periodically as they are pushing their dung ball to safety.
5) Once each student is oriented, they get back down and resume pushing their ball toward their burrow as before.

Stealer Beetles:

- The stealer beetles (those that are too lazy to make their own dung ball) hang out in the stealer zone trying to steal the ball of other beetles that enter the zone.
- Stealer beetles must also crab walk.
- A "steal" takes place when the stealer beetle is able to push the dung ball away from the other beetle and then take control enough to push it outside the stealing zone.
- The beetle that has control of the dung ball when the ball crosses the line and leaves the stealer zone is the owner of that ball and gets to continue pushing it to their burrow.
- When the ball itself leaves the stealing zone, the beetle not in control of the ball becomes (or continues to remain) trapped in the stealer zone (until they successfully steal a dung ball).
- Steeler beetles become frozen for 10 seconds when the whistle blows, while the other beetles are up doing their orientation dance, and they cannot steal during this time. Once the 10 seconds is up, they become unfrozen and can steal, which may become easy if the ball's owner has not finished orienting themselves and their ball is left unattended.

Adding Light Pollution:

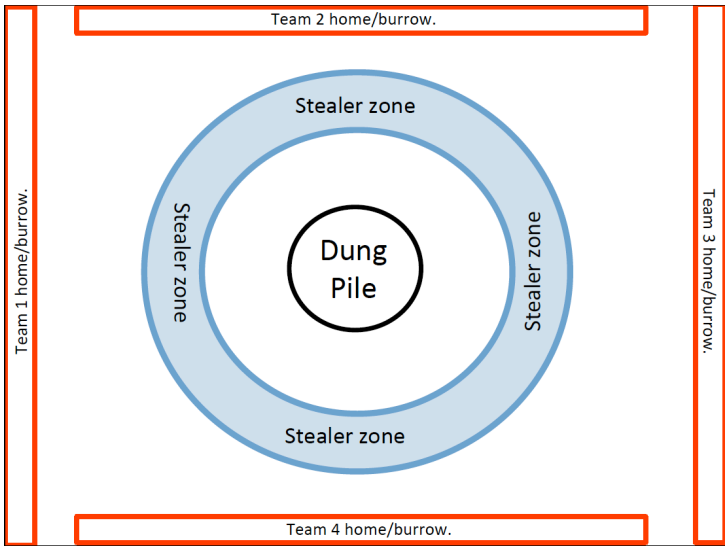
Periodically, or at least at one point during the game, the lights in the room

are turned on, simulating the light pollution caused by humans. The game otherwise continues as usual. The light pollution makes it harder for the beetles to orient themselves, however, which may make it easier for the stealer beetles to steal their dung ball if they cannot find and orient their arms in the direction of the Milky Way in time.

Winning:
Once all the dung balls have reached a burrow, the team with the most dung balls has had the most positive impact on global warming and wins the game.

Adaptations:

- In a school gym or large enough room, you start with a dung pile in the center of the room and as many as 4 teams that must move outward to one of the 4 walls. The "stealing zone" could be a circular zone part way between the dung pile and the walls. See game field layout below:



- Try outside in a field, with potentially even large numbers of dung beetles (students) using large balloons partially filled with water as the dung balls. Use cardinal direction signs/props and a moderator holding a sign to signal to players what orientation they must mimic with their arms (For example, mark N, E, S, W with large signs on the 4 sides of the field. At each whistle blow, the moderator has their own set of signs to hold up showing either "N-S", "E-W", "SE-NW", or "NE-SW", and the players have to figure out which two directions to correctly point to with their arms before continuing. Simulate the light pollution by first holding up the directional signs with white-on-black or black-on-white and when there is light pollution, hold up signs with white-on-light gray or light gray-on-white, or have multiple moderators with signs and change up which moderator holds the sign, so it takes the beetles longer to find the sign.

	• To keep the game going for longer, each team can keep score with the number of dung balls they bring to their goal/home and the teachers can put the dung balls back in play at the dung pile for new beetles to come and take. A beetle that has successfully taken a dung ball to their goal can "tag" a stealer beetle on their team, who can then leave the stealing zone to start rolling an "unclaimed" ball at the dung pile. The successful beetle who just tagged the stealer becomes a new stealer. • In one test group of ~2-4th graders, we required the kids to chant "Chugga-chugga chugga-chugga poo-poo" at the end of their orientation dance before beginning to roll again, and it was kind of hilariously awesome. Depending on the age and group, adding a humorous song/chant like this may help with memory retention of the process, as it adds an additional component to the fun and hilarity ensued.
Inter-Disciplinary Connections Ideas	**Literature Connections:** 1. Aesop's Fable "The Dung Beetle and the Eagle" 2. *The Metamorphosis* by Franz Kafka 3. *Everyone Poops* by Taro Gomi 4. "The Gold-Bug" by Edgar Allan Poe 5. *Every Dung Beetle Rolls Poop* by Craig Fischer **Earth and Space Sciences:** 1. Research the greenhouse gases that have the largest impact on global warming and human versus natural causes for these gases. 2. Research the changes in light pollution over time. Who/what else is hurt by light pollution? Make observations in your city/community/or neighborhood. Can you find sources of light that are acting more of a pollutant than help? How could we work to reduce light pollution? 3. Research motions in the sky over time. Would dung beetles in some parts of the world have a harder time using the Milky Way as a guide than others? Why/why not? **Life Sciences:** 1. Research other symbiotic relationships humans have with insects (e.g., honey bees). What are humans doing to help/hurt this relationship? 2. Rolling dung beetles can roll dung balls many, even thousands of times their own size and weight. (e.g., http://www.theguardian.com/environment/2010/mar/24/dung-beetles). Research other insects with "super hero" abilities. **Math/Computer Science:** 1. Complete the Random Walk Challenge. (Coming soon). 2. Complete some light pollution, energy saving calculations. If light

	were all directed down instead of in all directions… (Word problems coming soon.) 3. Play the National Geographic Kids Dung Beetle Derby game: http://kids.nationalgeographic.com/games/puzzles/dung-beetle-derby/
Supplements	Dung Beetles Using Polarized Light for Navigation Coming Soon.
References	**Acknowledgments** This OSU MAIL Box Lesson is based on an outreach activity, "Beetles Under the Stars", developed for use at the OSU Planetarium and the Columbus Metroparks in collaboration with the P.M. Sutter (OSU Department of Physics) and Z. Benderlioglu (OSU Department of Evolution, Ecology, and Organismal Biology). The construction and implementation of this lesson was made possible by the support of NSF AAPF grant AST-1302093 to KDD. **Primary (Research) References:** Dacke, Marie; Baird, Emily; Byrne, Marcus; Scholtz, Clarke H.; Warrant, Eric J. (2013). "Dung Beetles Use the Milky Way for Orientation". *Current Biology* **23** (4): 298–300. doi:10.1016/j.cub.2012.12.034 Losey, J. E.; Vaughan, M. (2006). "The Economic Value of Ecological Services Provided by Insects". *BioScience* **56** (4): 311–323. doi:10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2 Brown, J.; Scholtz, C. H.; Janeau, J. L.; Grellier, S.; Podwojewski, P. (2010). "Dung beetles (Coleoptera: Scarabaeidae) can improve soil hydrological properties". *Applied Soil Ecology* **46**: 9. doi:10.1016/j.apsoil.2010.05.010 Penttilä A, Slade EM, Simojoki A, Riutta T, Minkkinen K, et al. (2013) Quantifying Beetle-Mediated Effects on Gas Fluxes from Dung Pats. PLoS ONE 8(8): e71454. doi:10.1371/journal.pone.0071454 Dacke, M.; Nilsson, D. E.; Scholtz, C. H.; Byrne, M.; Warrant, E. J. (2003). "Animal behaviour: Insect orientation to polarized moonlight". *Nature* **424** (6944): 33. doi:10.1038/424033a **Secondary (Popular Media) References**: Dell'Amore, Christine. "Dung Beetles Navigate Via the Milky Way, First Known in Animal Kingdom". *News Watch*. National Geographic Society. http://voices.nationalgeographic.com/2013/01/24/dung-beetles-navigate-via-the-milky-way-an-animal-kingdom-first/ Roach, John (2003). "Dung Beetles Navigate by the Moon, Study Says", *National Geographic News*. http://news.nationalgeographic.com/news/2003/07/0702_030702_dungbeetle.html Ihaka, James (24 September 2010). "Let's roll... dung beetle to combat global warming". *The New Zealand Herald*. http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10675713 Holland, Jennifer (4 September, 2013). "Can Dung Beetles Battle Global Warming?".

	Nathional Geographic . http://news.nationalgeographic.com/news/2013/09/130904-dung-beetles-global-warming-animals-science/ **Videos:** http://www.ted.com/talks/marcus_byrne_the_dance_of_the_dung_beetle - t-165114 http://video.nationalgeographic.com/video/weevil_acorn?source=relatedvideo Humorous but slightly more inappropriate… https://www.youtube.com/watch?v=Q1zbgd6xpGQ