ABSTRACT
Soils contain a vast biodiversity of organisms with critical roles in maintaining ecosystem health, which remains unknown to many students. Soils are also a system well-suited to introduce broader ecological concepts such as ecosystem services and the links between biodiversity and ecosystem function. In the game Life for the Loam, designed for students in grades 6–12 and early undergraduate audiences, students strive to build the healthiest soil by introducing creature cards to boost their soil’s structure, nutrients, and food web. Gameplay introduces students to a wide array of soil organisms, and the ecosystem services each provides, and lets them build diverse communities for maximum environmental benefit.

Key Words: soil ecology; soil health; ecosystem services; biodiversity.

Introduction
Soils are extremely biodiverse, with high species richness of microbes, nematodes, earthworms, arthropods, and other organisms (Giller, 1996; Origiazzi et al., 2016). These organisms perform vital and valuable ecosystem services (Nielsen et al., 2015; Wall et al., 2015). Yet despite their importance, many soil organisms are almost unknown outside of scientific literature. In addition, students commonly hold misconceptions about soil and soil processes like decomposition, believing it to be a wholly physical or chemical process instead of involving animals and microbes (Causal Patterns in Science, 2008) or that the remains of dead plants and animals simply disappear instead of being broken down to provide nutrients for the soil (Helldén, 1995; Asshoff et al., 2020). They also may perceive soil as inert or dead, hardly the impression anyone should hold in a society so dependent on soil.

To fill this gap, we developed Life for the Loam, an educational game communicating key aspects of soil biodiversity and ecology to grades 6–12 and early undergraduate audiences. Games can enable cooperative learning and increase social interaction between student players (Nadolski et al., 2008; da Silva Júnior et al., 2020), as well as aid with student learning of subject matter (Cheng & Annetta, 2012; Girard et al., 2013; Cagiltay et al., 2015). Recent years have seen several novel physical games developed specifically for science classroom use (Hopwood et al., 2013; Gibson & Cooper, 2017; Cosme et al., 2020; Martindale & Weiss, 2020; Wibking, 2020). In Life for the Loam, players compete in groups of five to build the healthiest soil with the help of animals and microbes. The game and associated activities align primarily to the Next Generation Science Standards (NGSS) Disciplinary Core Idea “Biodiversity and Humans” (LS4.D) and NGSS Crosscutting Concepts “Systems and System Models” (National Research Council, 2012).

Background
A playthrough of Life for the Loam is an effective introduction to soil biodiversity and ecology, though the game can also be played after a lecture or reading introducing the topic. A pre-game introduction should include some or all of the following information.

Soil has many definitions (Hartemink, 2016). In physical terms, it is the coating of mineral and organic material covering much of the Earth's land surface. In practical terms, it is an important resource for human society. Soils support plant growth, store water, and can even sequester greenhouse gases (Nielsen et al., 2015). These ecosystem services are mediated and, in some cases, provided entirely by soils vast diversity of animals and microbes (Nielsen et al., 2015; Wall et al., 2015). Three key functions of soil organisms are decomposition and nutrient cycling, water storage and filtration via a porous structure, and suppression of pests and pathogens.
Microbes are responsible for most organic matter breakdown in soil (Seastedt, 1984). With few exceptions, plants cannot take up nutrients from organic matter, instead relying on inorganic, ionic forms of nutrients (nitrate, phosphate, ammonium, etc.) present in the soil, so decomposition is important for nutrient availability (Manzoni et al., 2008). Animals that feed on microbes, such as springtails and some nematodes, and ones that feed on organic matter itself, such as isopods and millipedes, influence microbial function and the decomposition process in other ways. These include stimulating additional microbial growth through direct grazing, dispersing microbes through the soil, and physically and chemically altering pieces of organic matter via consumption, gut fragmentation, and excretion (Seastedt, 1984; Wickings & Grandy, 2011; Yang et al., 2020).

Soil organisms also maintain a porous and stable soil structure that lets roots grow, animals move, and water flow without obstacle. This improves the soil’s ability to support plant growth and store water, which reduces surface runoff and flooding. Many macroinvertebrates aerate the soil through their burrowing and tunneling activities. The most effective of these, such as earthworms and ants, are often called ecosystem engineers (Lavelle et al., 1997). Though microbes are too small to manipulate soil’s physical structure, thread-like fungal hyphae and sticky bacterial secretions can keep aggregates bound together and improve soil stability (Harris et al., 1964; Forster, 1990).

Finally, diverse soil communities can suppress crop pests and pathogens. Certain microbes found in or near plant roots can outcompete or directly attack plant pathogens (Whipps & Gerlagh, 1992; Datnoff et al., 1995) or induce increased immune function in the plant (Sharma & Sharma, 2017). Predatory organisms like spiders and ground beetles may also prey directly on pest species.

In addition, soil biodiversity is often more than the sum of its parts. More diverse communities tend to deliver ecosystem services more effectively due to different species providing the service in complementary ways (Snyder et al., 2006; Manning et al., 2016) and are more resilient in the face of some disturbances (Mace et al., 2012; Nielsen et al., 2015).

### Materials & Gameplay

Full instructions and printable game materials are available in the Supplementary Material with the online version of this article and via Google Drive (https://drive.google.com/drive/folders/1cfLb8dyprKAXxhel05yw5NLmWfylGCGL). Each print-and-play includes the 144 creature cards (Figure 1), 4 season cards (Figure 2), and 30 bonus cards (Figure 3) needed for a single group of five students, as well as soil stat trackers and stat counters to help students keep track of their soil’s structure, nutrients, and food web. A free, digital version of Life for the Loam is also available via Screentop.gg (https://screentop.gg/@Vermivorax/loam-class). Screentop.gg enables online multiplayer gameplay when combined with voice or video chat.

### Table 1. List of Life for the Loam’s learning objectives and related game mechanics.

| Learning Objective                                      | Basic Information                                                                 | Associated Game Mechanic                                                                 |
|--------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Biodiversity of soils                                  | Soils are extremely biodiverse, with high species richness of microbes, nematodes, earthworms, arthropods, and other organisms (Giller, 1996; Origiazzi et al., 2016). | Creature cards representing 102 soil organisms.                                         |
| Ecosystem services provided by soil organisms          | Soil organisms perform valuable services for soil, including decomposing dead organic matter, improving the stability of soil’s structure and its ability to admit air and water flow, and keeping pests and pathogens in check (Nielsen et al., 2015; Wall et al., 2015). | Creature cards representing organisms’ function in soil via their indicated effects on soil structure, nutrients, and food web. |
| Links between biodiversity and ecosystem services      | Higher biodiversity generally leads to increased provision and stability of ecosystem services (Nielsen et al., 2015; Wall et al., 2015). | Community bonus cards players may claim after assembling groups of creatures with specific characteristics. |

![Creature Card Example](image_url)
but this requires a computer and reliable internet connection, so we recommend ensuring your students are all able to access the game before incorporating it into a course. We also include in the Supplementary Material a brief explanation of the Screen-top.gg platform and how to get students started with the digital game.

Assessments

After playing the game, ensure students do not immediately shuffle their creature cards back into the deck. Some of our suggested discussion/assessment exercises (Table 2) involve students analyzing their assembled communities, predicting their properties and ability to provide ecosystem services in the face of environmental disturbances, and comparing them to one another. Completing

Table 2. Discussion and assessment questions to give to individual students and/or small groups.

| General Exercises |
|-------------------|
| 1. Which two seasons see most biological activity within soils of temperate regions? Why? |
| 2. What are the differences between how plant mutualists and animal decomposers provide nutrients, how microbial decomposers and ecosystem engineers improve structure, and how plant mutualists and large predators improve food webs in real-life soils? |
| 3. Why is decomposition important for ecosystems? |
| 4. If you came across a new species of soil animal and had a chance to observe its anatomy and behavior, how might you infer what ecosystem services it could provide? |
| 5. What are some ways even two very similar organisms (for example, two species of woodlouse) could provide the same ecosystem service in slightly different ways? |
| 6. Come up with as many types of material as possible that could qualify as “soil organic matter.” |

| Exercises Involving Game Components |
|------------------------------------|
| 1. Consider the two communities you assembled on your soil. Which ecosystem service(s) (structure conditioning, nutrient provisioning, and pest/pathogen control) would each be best and worst at providing, or would they be well-balanced between the three? Why? |
| 2. Design an experiment you could conduct to test which of your communities provides one specific service (structure conditioning, nutrient provisioning, and pest/pathogen control) most effectively. In particular, how would you measure how well each community provides the service? |
| 3. How stable do you think your two communities are? If any single creature or all creatures of one type were removed, would each still be able to provide the service(s) it does? |
| 4. Arrange the creature cards in both of your communities into a food web on a sheet of paper, with soil organic matter at the bottom left, plants on the bottom right, and pest organisms above plants. Draw arrows indicating what organisms consume what. |
these assessments will further allow the students to develop a more nuanced outlook on how biological features figure into soil structure and function. Potential answers to these exercises are included in the Supplementary Material. We suggest students be evaluated on their performance/participation in these exercises rather than their game performance.

Acknowledgements

We thank Zoe Getman-Pickering for art assistance with one of the game’s creature cards. Playtesters at various stages of the game’s development include Kyle Akred, Robin Fisher, Rebecca Schmidt, Elizabeth Szczepanski, Allison Zahorec, Keith Koontor, Tim Lampanosa, Errol Kuppelian, Jordan DelFiero, James Chartreuse, Ada Korman, and Sam Grieshop. We also thank Rachel Osborn, Dan Turner, Zinan Wang, Joe Receveur, Ryan Kimbirauskas, and Gabe Ording for their assistance and cooperation incorporating an earlier version of the game into a lab course at Michigan State University in the spring semester of 2020. Funding for this project was provided by the Sustainable Michigan Endowed Project and the Michigan State University Graduate School.

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