In this lesson, students learn about how simple organisms can solve complex problems via a collective intelligence known as *swarm intelligence*. The lesson begins with an active simulation in which students see first-hand what can happen when a group follows simple rules. They then explore the concept of swarm intelligence in detail through examples of collective group behavior in ants, starlings, and honeybees. Next, they consider what scientists have discovered about coordinated systems in nature, and they look at how key principles of swarm intelligence can be applied to smart devices and in computing to solve complex human challenges, such as increasing energy efficiency in commercial buildings and using robots for rescue missions.

Co-authored by the Biomimicry Institute.

**KEY OBJECTIVES FOR STUDENTS:**

- Explain how swarm intelligence enables groups of organisms to efficiently and effectively solve complex problems using simple rules.
- Provide examples of organisms that exhibit swarm intelligence.
- Describe key, coordinated behaviors that bees use to select a new location for a hive.
- Explain how principles of swarm intelligence can be applied in human systems and computing.
- Provide examples of biomimetic products inspired by swarm intelligence.

**ESTIMATED TIME NEEDED (MINUTES):**

- 55 minutes

**GRADE LEVELS:**

9, 10, 11, 12

**PRIMARY SUBJECTS:**

- Environmental Education
- Science

**SECONDARY SUBJECTS:**

- Biology
- Career Technical Education (CTE)
- Social Studies

**TOPICS:**

- Biomimicry
- Sustainability
- Design in nature
- Collective problem solving
- Swarm intelligence
- Swarm theory
- Swarm logic

**METHODS:**

- Brain-Based Learning
- Design Thinking
- Multi-Disciplinary
- Multiple Intelligences
- Real-World Application
- Technology Integration

**SKILLS:**

- Collaboration
- Communication skills
- Creative problem solving
- Critical Thinking
- Systems thinking

**VALUES:**

- Curiosity
- Mindfulness
- Resilience
PREPARE

BACKGROUND INFORMATION FOR TEACHERS:
Human technologies and organizational systems tend to operate with a top-down control structure. From hierarchical business structures, to central computers, we expect somebody, or something, to be “in charge.” However, in nature, many groups of organisms exhibit complex behaviors and seemingly intelligent coordination of their activities without central control. These self-organizing systems are also remarkably efficient and effective. As researchers learn more about how these systems work and the often simple rules that drive them, we have the opportunity to apply those insights to the design of “smart systems” that could make our cities, organizations, and utilities run better.

PREVIOUS SKILLS NEEDED:
Cooperative learning skills, brainstorming skills, listening skills

IN ADVANCE:
Review the Swarm Intelligence and Smart Systems Presentation and accompanying Teacher's Notes. Read the "Cooling Off with Swarm Logic" Article and make a copy for each student. Also make a copy of the Swarm Intelligence and Smart Systems Student Notes for each student. You may also want to have several copies of the "Cooling Off with Swarm Logic" Sample Answers available for students to check their work. Set up and test the equipment needed to share the presentation.

MATERIALS NEEDED:
- Computer and presentation equipment

KEY VOCABULARY:
biomimicry
biomimic
swarm intelligence
decentralization
self-organization
energy efficiency

⚠️ SAFETY INFORMATION:
Instruct students to exercise caution and not bump into each other or objects when moving around in the initial simulation.
ACTIVITY OUTLINE:

<table>
<thead>
<tr>
<th>Time</th>
<th>Exercise</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min.</td>
<td>Introductory Activity</td>
<td>Students participate in a simulation in which they apply simple rules.</td>
</tr>
<tr>
<td>5 min.</td>
<td>Discussion</td>
<td>Lead a discussion that helps students reflect on what they learned from the simulation.</td>
</tr>
<tr>
<td>20 min.</td>
<td>Presentation</td>
<td>Show students the presentation, and have them complete the student notes sheet as they watch.</td>
</tr>
<tr>
<td>15 min.</td>
<td>Article</td>
<td>Students read an article and answer analysis questions about it.</td>
</tr>
<tr>
<td>5 min.</td>
<td>Wrap-Up</td>
<td>Ask students to reflect on human applications of swarm intelligence; answer any remaining questions students may have.</td>
</tr>
</tbody>
</table>

IMPLEMENTATION:

1. **Introductory Activity:** Take students to a location that has plenty of space for them to move around safely, such as a courtyard, cafeteria, gym, wide hallway, etc. Ideally, this will be a space that is at least 4.5–6 m (15–20 ft.) across. Identify clear boundaries to define the area that students can move around in.

2. First, instruct each student to randomly and *silently* choose two other people in the class—Person A and Person B—but to not indicate to anyone who they chose.

3. Tell students that as they move around the designated area, they need to follow one simple rule: Keep Person A in between themselves and Person B; A is their “protector” from B. Allow students to move around the area for 2–3 minutes using this one rule. Students will appear to move around randomly without anything notable occurring.

4. Tell students to stop. You’d like them to repeat the activity, but this time the rule is for them to be the protector. So as they move around, they need to keep themselves between Person A and Person B. Allow students to move around the area for 1–2 minutes as they apply the new rule. Very quickly, everyone will begin to cluster together and the rule will be almost impossible to follow.

5. **Discussion:** Ask students to describe what happened during the simulation. *(In the first round, the group quickly spread out. In the second round, we quickly came together.)* Encourage discussion about how a simple rule change governing individual behavior impacted the behavior of the entire group. Point out that simple rules can have a significant impact on a system, and small changes to those rules can lead to dramatic consequences. Ask: Did you expect that applying the second rule would have such dramatic result? *(no)* Your intuition probably suggested that the results would be similar to those we got when you applied the first rule, right? *(yes)* Explain that conducting a simulation can be a powerful way to model behavior within complex systems.

6. **Presentation:** Show students the Swarm Intelligence and Smart Systems Presentation, using the accompanying Teacher’s Notes to guide discussion. To help students organize and summarize their learning, give each student a copy of the Swarm Intelligence and Smart Systems Student Notes, and ask them to answer the questions as they view the presentation. After the presentation, give students time to work alone or with a partner to complete the student notes.

7. As a class, review students’ responses to the questions on the Swarm Intelligence and Smart Systems Student Notes.

8. **Article:** Direct students to read the “Cooling Off with Swarm Logic” Article independently or out loud with a partner. Give students time to work alone or with a partner to complete the review questions that follow the article. Circulate and answer any lingering questions they may have.

9. **Wrap-Up:** Ask students to reflect on human applications of swarm intelligence, including how swarm intelligence differs from traditional, centralized, top-down approaches to problems. Prompt students to think about how swarm intelligence could be applied beyond industry and the military and used in systems of government. Answer any remaining questions students have.
REFLECT

REFLECTION QUESTIONS:
Use the following questions to prompt critical thinking and guide students to reflect about the lesson:

- How can simple rules governing individual behavior affect behavior at the systems level? *(Sample answer: As we saw in the introductory activity, small changes in the rules of interaction can have a huge impact on the way a system operates. When the rules changed in the activity, the group behaved in an entirely different way.)*

- In the case of beehive identification, why is collective problem solving by the entire swarm more effective than the queen bee alone selecting a hive? *(Sample answer: The queen bee is simply unable to identify as many potential hive sites as hundreds of bees. In addition, the queen may be biased or incapable in some way and make an error or a decision based on her own self-interest rather than the needs of the colony as a whole.)*

- What can we learn from the bee colony’s collective problem-solving techniques that we can apply to human systems? *(Sample answer: We can use what we’ve learned from bees to analyze different systems of government—e.g., a democracy is more like swarm intelligence, for every citizen gets a vote using a secret ballot; whereas dictatorships follow a top-down approach that does not harness the power of collective problem solving.)*

- How can the principles of swarm intelligence be applied in our classroom, our school, or our community to increase both efficiency and inclusivity? *(Sample answer: In our classroom, we could solve problems by allowing every student to brainstorm and propose as many solutions as possible. We could discuss and evaluate those options and then vote to determine the most popular option. So instead of the teacher choosing one solution, we would all work together to identify and choose the best solution for the classroom as a whole. We could use a similar process for the school and the community.)*

ASSESSMENT OPPORTUNITIES:
Give each student a copy of the Swarm Intelligence and Smart Systems Student Notes Sample Answers and the “Cooling Off with Swarm Logic” Article Sample Answers to help them evaluate their own comprehension of the main ideas from the presentation and the article. Alternatively, you could assign the Swarm Intelligence and Smart Systems Student Notes and/or “Cooling Off with Swarm Logic” Article Review Questions as a graded assessment. The Reflection Questions on the Assess Tab also provide an excellent opportunity to assess students’ comprehension of the material; you can document student progress using a checklist during a group discussion of the questions or assign the questions as a written quiz. In addition, the material on the Extend Tab is useful for further checking student comprehension as well as for reteaching and extending key ideas from the lesson.

STANDARDS ASSESSMENT:
This lesson, with all components included, is linked to the following standards:

**Common Core State Standards (CCSS)**


**Grades 11–12:** RI.11–12.1, RI.11–12.2, W.11–12.1a–e, W.11–12.2a–f, W.11–12.4–8, SL.11–12.1a–d, SL.11–12.2–6, L.11–12.1b–c, L.11–12.2a–c, L.11–12.3a, L.11–12.4a–d, L.11–12.5a–c, L.11–12.6, RST.11–12.1–4, WHST.11–12.1a–e, WHST.11–12.2a–f, WHST.11–12.4–10

**Next Generation Science Standards (NGSS)**

**Middle School:**
Ecosystems: Interactions, Energy, and Dynamics: MS-LS2-2

**High School:**
Earth and Human Activity: HS-ESS3-2

**Cloud Education for Sustainability (EiS) Standards & Performance Indicators**

**Grades 3–12:** B4, C1, C4–C10, C13–C16, C18, C28, C29, C32, C34, D7, F2, F3, G1, G5, H11, I35

**Texas Essential Knowledge & Skills (TEKS)**

**Biology:** §112.34.c.7.E, §112.34.c.10.A–C, §112.34.c.11.A, §112.34.c.12.A,B

**Estándares Secretaría de Educación Pública (México):**

**Secundaria:**
Español: LIT.SE.1.1, 1.2, 1.4, 1.7, 1.8, PTE.SE.2.1–2.11, PTOECO.SE.3.1–3.6, FUL.SE.4.1, AL.CE.5.2–5.7, 5.10, 5.11
Ciencias: CC.SE.1.12, ACT.SE.2.1–2.5, AC.SE.4.1–4.3, 4.6, 4.7

**Estándares Secretaría de Educación Pública (México):**

Bachillerato:
BA.CG.1.1, 1.2, 1.3, 2.4, 3.5, 3.6, 4.7, 5.8, 6.9, 6.11
BA.CDB.C.4.1, 4.3, 4.4, 4.5, 4.6, 4.7, 4.9, 4.12
BA.CDE.CE.1.11.9, 1.12, CO.2.1, 2.3, 2.7, CS.3.3
COMMUNITY CONNECTIONS:
Arrange for a beekeeper to visit the classroom, or arrange a field trip to a farm that houses beehives. Ask students to come up with a list of questions in advance about swarm behavior as it relates to both hives and the identification of nectar sources. Ask the beekeeper to explain how he or she designs artificial hives and gets the bees to colonize them.

CROSS DISCIPLINARY CONNECTIONS:

Social Studies
Have students select and research a form of government and then analyze its effectiveness by comparing and contrasting it to the honeybee’s principles of swarm intelligence. Encourage them to focus their analysis on the principles of decentralization, diversity of opinion, lack of conformity, and a decision-making process that balances accuracy with speed. Encourage students to work cooperatively to come up with a creative way to share their findings.

Language Arts
Suggest that students research additional human applications of swarm intelligence and write an expository essay on the costs and benefits of at least one application. Students could compare and contrast that human application to the swarm behaviors of bees, ants, or starlings. Encourage them to describe how the human application differs from the more traditional top-down, centralized approach that it replaced. The article “How the Science of Swarms Can Help Us Fight Cancer and Predict the Future,” from Wired magazine, offers several examples and could serve as a starting place in helping students to choose a topic.