USING FISH SCHOOLING TO EXPLORE SELF-ORGANIZATION
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Lesson Overview
The goal of this activity is to introduce students to basic concepts underlying self-organization through enactment. Students will pretend to be fish and follow simple rules of interactions to mimic fish schooling. Students will then discuss their observations of individual and group behavior during this activity to explore the basic properties of a self-organizing system.

Learning Objectives
• Explore cross-cutting concepts such as pattern formation, scale and dynamics, which are part of the Next Generation Science Standards
• Build observation and analytical skills
• Learn to communicate information

Timeline
• 10 minutes for introduction
• 20 minutes for schooling activity
• 20 minutes for discussion and analysis
• 20 minutes for modifications of schooling activity (optional)

Requirements
• 15-30 students (minimum of 10 students)
• Open playground or field (approx. 800 sq. ft. for 15 students)
• Camcorder to video student schooling (optional)

Procedure
1. Introduction
Start this activity with basic information about fish schooling and self-organization to help students learn from this exercise. Key topics to cover in the Introduction are:

a) The specific question explored in this activity is how thousands or millions of individual fish swim together as a coherent unit (school) in the absence of a leader or plan. Showing videos of fish schooling is an effective way to get students to appreciate the highly dynamic nature of fish schools.

b) This question will serve to illustrate the broadly applicable concept of self-organization—the process by which patterns emerge through simple interactions between the basic units or building blocks of a complex system. Emphasize that the individual subunits respond only to local information, they are blind to the overall pattern. For example, a fish simply responds to its neighboring fishes in a school; it doesn’t “plan” its response based on the existing school shape or size.

c) Introduce basic fish behavior. Fish perceive other fish through vision and the lateral line system (a type of motion detector). In this activity, students will use vision and touch to detect nearby students. Fish are thought to follow certain rules that lead to schooling: (i) If a neighboring fish is too close → swim away a bit (repulsion), (ii) If another fish is near you → orient parallel to it (alignment), (iii) If another fish is too far away → swim towards it (attraction), and (iv) If you don’t see another fish→ turn randomly. Note: All fish exhibit the same behavior (that is, there is no leader).
2. Procedure
   a) Students will randomly choose their starting position in the playground/field. This should lead to some students being close together and other being farther apart. Depending on the size of the playground/field, students can stand with their hands either completely or partially stretched out. Their hands will serve as proximity sensors. Note: At this point, the students are standing in their starting position. They do not move until asked to (step c).
   b) Stress that students must follow the following rules when they start to walk: (i) If their hands touch another student’s hand → then take a step away, (ii) If their hands come close to another student’s hand (but not touching) → then align alongside that student, (iii) If hands are too far → then step toward the closest student. See figure below.

![Diagram of Repel, Align, Attract zones]

Besides these behavioral rules, there is also a boundary rule that students must follow: if a student reaches the end of the playground/field, they will turn away from the boundary. It is a good idea to do some dry runs to get the students comfortable following these rules.

   c) Have video recorder ready or assign a teacher (or 1-2 students) to monitor the schooling behavior.
   d) Give the signal for the students to start walking. Each student should ideally be moving as per the rules of interactions. Have an assistant ready to help students who are confused or ignoring the rules of interactions. Over time (usually about 5 min), students should group into one or more schools. Let the schooling proceed for at least 10 min to capture the dynamics and complexity of this process.

3. Wrap up
   Show the videos of this activity to the students or have teachers/students describe what they observed to prompt discussion of this exercise. Suggested topics to discuss are:
   a) How long did it take to self-organize into a school?
   b) Was a particular person always at the front of a school or did this change over time?
   c) Were students in the school aware of what the school looked like as a whole or the direction in which the school was moving over a period of time?
   d) Once a school formed, was its shape and size constant or did these features change over time?

Use the discussion to help students learn the basic characteristics of a self-organizing system: (i) simple interactions based on local information result in complex system-level patterns, (ii) there is no leader or blueprint that guides pattern formation and (ii) these patterns are highly dynamic.
4. **Additional Explorations**

The above activity can be used as a foundation for additional open-ended explorations of self-organizing systems. Some possible explorations are listed below:

a) **Repeat the activity:** Did the same schooling pattern emerge in **both** runs? How would you determine the likelihood of a given pattern to occur?

b) **Explore the effect of the rules of interactions:** What would happen if you changed the rules of interactions? For example, what would happen if you changed the way you align yourself with respect to your neighbor (how far away, at what angle, etc.)? Do these changes affect the ability to form schools? Do they affect the shape and size of schools? Alternatively, what would happen if you eliminated the rules entirely (i.e., individual students walked as they wanted and ignored other students)?

c) **Explore the effect of environmental perturbations:** What would happen if the school encountered a barrier? Would the school get fragmented? Does this depend on the size of the barrier?

d) **Explore the effect of fish density:** How does the number of students affect schooling? For example, does it affect the rate of formation and size of a school?

e) **Explore response to predators:** Schooling can facilitate evasive tactics in response to a predator. For example, fish in a school will coordinately swim away from an approaching predator in a maneuver called flash expansion. Try mimicking this by assigning one student to be a predator who approaches a school. Does the predator have better luck if he/she approaches the fish before or after a school has formed? Why?

5. **Suggested Resources**

- **Self-Organization in Biological Systems.** Authors: Camazine, Deneubourg, Franks, Sneyd, Theraulaz and Bonaneau. Princeton University Press, 2001. ISBN: 0-691-11624-5. This is a superb and very readable book that describes the basic properties of self-organization and provides many in-depth examples of self-organizing biological systems. Chapter 11 focuses on fish schooling and is a wonderful resource on this topic. Comparing and contrasting fish schooling to other self-organizing systems described in this book (e.g., bacterial aggregation, insect swarming, termite mound construction) can be very helpful to highlight features of self-organization that are conserved across different systems.

- **Links to fish schooling movies.**
  - [http://www.youtube.com/watch?v=ShZ7VNssM9o](http://www.youtube.com/watch?v=ShZ7VNssM9o) Shows lack of leader and changes in school shape over time.
  - [http://www.youtube.com/watch?v=tGOKngtkt4](http://www.youtube.com/watch?v=tGOKngtkt4) Shows schooling and flash expansion.