Math and Nature

* The dawn of the scientific age coincided with the realization that nature can be described through math. As stated by Galileo in 1623, the entire universe is written in the language of mathematics. Since this time, quantitative analysis of natural phenomena has been at the heart of scientific inquiry. Owing to this relationship between natural phenomena and its description via mathematics, nature provides a tangible context for math that can be used to invite students into math instruction. Nature provides context, which is essential to developing interest in a subject. As educators, it is our responsibility to generate this interest.

The Importance of Context

* In writing, context is the setting in which a story occurs. In many ways, the setting gives meaning to the details of the story and is therefore essential to the development of the plot. As educators we are, in a sense, storytellers that can use context to invite students into the material we are teaching about. Because of this, we believe that many of the components of good story-telling can be used to improve student engagement and knowledge in the classroom.
  + A lack of context is one of the more common complaints about math education because students are always wondering why the mathematical topic is relevant. Context establishes relevance.
* Pedagogical research has shown that creating context for information allows students to relate their own experiences to the material, facilitating experiential and associative learning. This was described by Merrill (2002):
  + First Principles of Instruction:
    1. The demonstration principle: Learning is promoted when learners observe a demonstration.
    2. The activation principle: Learning is promoted when learners activate prior knowledge or experience.
    3. The application principle: Learning is promoted when learners apply the new knowledge.
    4. The task-centered principle: Learning is promoted when learners engage in a task-centered instructional strategy.
    5. The integration principle: Learning is promoted when learners integrate their new knowledge into their everyday world.
  + The demonstration of new knowledge within a relevant context activates students’ prior knowledge of the subject, which engages them in the material at hand. Once engaged, students are given the opportunity to apply this new knowledge in a task-centered (problem-solving) manner. Association of new knowledge with prior knowledge reinforces this material in the memory, allowing integration of it into new experiences. Integration of knowledge into new experiences is the essence of problem-solving.

Geometry and Biology

* The use of nature as a context for math is extremely evident with regard to biology and geometry. Biological structures vary greatly in their geometry. Given that differences in the geometry of biological structures affect the function of those structures, biology provides a mechanism for geometric problem solving and for illustrating the consequences of geometric variability.
  + The consequences of geometric variability establish the functional aspect of biology, which is what really invites students into the problem. Given the extensive diversity of organisms, their function can provide context for most any math topic.
* Interestingly, behavior can also be analyzed with respect to geometry. Movements are behaviors caused by communication between the nervous system and musculoskeletal system, and involve geometric rearrangements of skeletal elements.

Jaw Protrusion

* Jaw protrusion is a feeding behavior exhibited by many shark and bony fish in which the upper jaw extends away from the cranium towards the prey item as the jaws are being closed. This behavior allows the predator to close the distance to its fleeing prey in the last moments of a predatory event, and plays a key role in the feeding ecology of many fishes.
  + Embedded video: Sandtiger shark *Carcharias taurus* using jaw protrusion to capture a fish. Note movement of upper jaw during biting.
* Jaw protrusion is possible in fish because the upper and lower jaws are suspended beneath the cranium, an arrangement which reflects the evolutionary history of jaws. Jaws evolved from a series of skeletal arches that surrounded the pharynx (region between the opening of the mouth and the opening of the digestive tract). These arches were used to pump the pharynx, which drew water and food particles into the mouth; this condition is still represented by jawless fish such as the lampreys. Some of these arches eventually rotated forward to form the jaws and the skeletal elements that suspend the jaws from beneath the cranium. This suspension allows the upper and lower jaws to move independently of the cranium.
* Jaw protrusion is not possible in terrestrial vertebrates because the upper jaw is fused to the skull. However, terrestrial vertebrates such as salamanders and chameleons have evolved the ability to protrude their tongues from their mouths to capture prey.
  + Visit [www.debanlab.org/movies](http://www.debanlab.org/movies) for remarkable videos of these feeding behaviors.

Batoid Jaw Protrusion

* Some batoids (stingrays & their relatives) protrude their jaws in a manner analogous to a “scissor-jack” that would be used to change the tire of a car. This “scissor-jack” mechanism can be modeled as a pair of isosceles trapezoids in which changes in the interior angles bring about changes in the overall length of adjacent trapezoids.
  + Ex: Lesser electric ray *Narcine brasiliensis*. This ray protrudes its jaws down towards the sediment in search of buried prey such as worms. The two isosceles trapezoids in its feeding mechanism are represented by:
    1. A trapezoid formed by the underside of the cranium, the two skeletal elements suspending the jaws from the cranium (hyomandibular cartilages labeled “hyo-“ on PowerPoint slides), and an imaginary line passing horizontally through the joints between the hyomandibular cartilages and the jaws.
    2. A trapezoid formed by the same imaginary line passing horizontally through the joints between the hyomandibular cartilages and the jaws, the right and left halves of the jaws, and a pad-like structure covered in teeth that connects the right and left halves of the jaws.
  + For videos of jaw protrusion in the lesser electric ray please contact Dr. Mason Dean at [mason.dean@mpikg.mpg.de](mailto:mason.dean@mpikg.mpg.de).
* By working through the PowerPoint exercise, students can determine the distance from which this ray can protrude its jaws to capture prey. Keep in mind that these distances are relative to the size of the ray. Much larger rays, such as the sixgill stingray *Hexatrygon bickelli,* are capable or protruding their jaws great distances, which gives them a significant predatory advantage.