Chapter Summary Questions
These questions can be used to help students identify and better grasp what was most important in each chapter. They could also be used for a quiz.

Before introducing the book
How can we learn from fossils?

- Throughout the book it becomes clear that fossils can be observed using our senses, but also with new technologies as they become available. We can also learn from the rock setting in which fossils were found and the surrounding fossils. Comparative anatomy is an important tool when learning about extinct life, too.

Introduction
What drew the author, who is not a scientist by trade, to write this book about science?

- Curiosity, serendipity and circumstance, p. 3.

Why does the author say the group of people involved in this book were "a quirky band of boundary-bending collaborators that looked more like a roots-rock band than ivory tower intelligentsia?"

- The people involved in this scientific investigation (artist Ray Troll, science student and tattooed veteran, etc) are not who we might typically think of as scientists, p. 3.

1: Lasting Impressions
This chapter sets the scene for a series of serendipitous geologic and human events that occured over immense spans of time that led to us to our current understanding of *Helicoprion*.

Why do scientists estimate that many, many more species of life existed on Earth than fossils represent?

- Fossils require certain conditions and most animals that die do not fossilize, p. 5-6.

True or false, when an animal is fossilized, all of its remains are found?

- False. Fossils are a rare occurrence and when they do form, they often only preserve portions of an animal's remains, p. 6.

Why would only the fossilized teeth of a shark be found (why not its ribs, spine, etc.)?

- Sharks "skeletons" are largely cartilaginous - a material believed not to fossilize.

Why were only 32 of the 140 dinosaur species Marsh and Cope identified during their "Bone Wars" proven valid?

- Many of the species identified as new by Marsh and Cope were actually additional fossils of already identified species, p. 8.

2: The Shark Bites

This chapter explores the origins of important principles in geology that are key to our later understanding of *Helicoprion's* place in the fossil record and geologic time.

How was it determined that fossils were remains of past life?

- Steno and Hooke both compared remains from living (or recently dead) animals to items found inclosed in rocks. p. 24-27

What is a Chedworth bun and how does it relate to fossils?

- Chedworth buns are fossilized sea urchins that look like baked rolls, P. 28.

Explain the Principle of Superposition in geology.

- Any layer, as originally laid down, is younger than the layer it rests on and older than the one above it. P. 26

What is faunal succession?

- Unique fossils sets in rock layers succeed one another. P. 33

How did observation of evidence lead to William Smith's understanding of faunal succession?

- William Smith observed repeating patterns of rock and fossil layers in mine shafts. P. 30

<u>3: Right Shark, Wrong Name</u>

This chapter explores how living and extinct animals are classified and how scientists use comparative anatomy as a means to place extinct animals in the tree of life.

How did Henry B. Woodward misidentify evidence in a photo of the Australian fossil?

- He identified what are now known to be teeth as fin spines and published about it in his journal Geological Magazine. P. 48

What is the two name system devised by Carl Linnaeus to classify plants and animals and what does each part of that system refer to?

- Linnaeus proposed a system with two names - genus and species. Genus, similar to a last name, designated the race or stock and first name, species, referred to the specific or particular kind - referencing something specific about the organism. P. 49

What are all eight levels used for classifying animals and plants?

- From broadest to most specific: domain, kingdom, phylum, class, order, family, genus, species. P. 50

What is the class in which all fish with cartilaginous skeletons (including sharks) belong?

- Chondrichthyes. p.51

What does the word homologous mean in comparative anatomy?

- Homologous structures are structures that are the same. A bone may be modified over time and evolution, but matches a bone from an ancient ancestor, P. 55

How are divergent and convergent evolution different in terms of comparative anatomy?

- Divergent evolution is when two species evolve from a common ancestor to become very different. Convergent evolution is when two very different species (who don't share a common ancestor) evolve similar features or behaviors (like bats and birds), P. 55.

What is the difference between analogous and homologous structures in comparative anatomy?

- Analogous structures are similar structures that evolved convergently (like bat and bird wings) on animals that don't share a common ancestor. Homologous structures may look very different on two species, but are the same structure evolved over time (like the humerus on a coelacanth and a human), P. 55.

In 1868 Leidy worked with a sculptor to create a display of real dinosaur bones. What was significant about this event?

- The hadrosaur was articulated (put together) rather than a display of isolated bones. It was also on two legs. The public was able to image the animal in life and the display was very popular. P. 57-58.

<u>4: First Cousins</u>

During the second half of the 1800's, several individuals observed fossil evidence and presented well-supported arguments as to what the fossil represented - teeth or fin spines.

What evidence caused Leidy to think that his fossil came from the upper jaw of a shark?

- Leidy made comparison between the structure which he believed to be a segmented upper jaw of a shark, and the segmented upper jaw of Devonian lobe-finned fish in the *gar* family, p. 62.

Why did the bilateral symmetry of the fossils confuse researchers and cause them to believe they were not teeth?

- Examples of bilaterally symmetrical teeth were not known. Other shark teeth were not bilaterally symmetrical. This led researchers to believe the teeth were fin spines, p. 65.

How did the Civil War affect the study of fossil sharks?

- During the time of the Civil War researchers put their fossil projects on hold and participated in war time efforts, p. 67.

What is denticle?

- A denticle is a modified scale made of calcified material (very similar to tooth material) embedded in sharks' skin, p. 67/68.

What arguments based on fossil evidence does Newberry provide supporting fin spines?

- Sharks do not have symmetrical teeth (fossils were symmetrical), sharks teeth are attached by ligaments (fossils attached by bony base), fossil unlike jaw of any fish, reptile or mammal known, rough rounded base must have been implanted in skin like denticles, not attached to bones or cartilage, p. 69.

5: Whorl of Fortune

In this chapter the author introduces new fossils and an important new researcher, Karpinsky. Both the fossils and Karpinsky are from Russia. The chapter turns into a tour of geologic time and picks up with Karpinsky's role as a geologist again at the beginning of chapter 6.

How and where were new and more complete tooth whorl fossils found?

- Around 1898 at the Divya Gora limestone mine in the Ural Mountains of Russia in a town called Perm. The rocks in the mine were Permian in age (about 299-252 million years old), p. 76-78.

The geologic timescale is described from pages 81- 93. At what point in geologic time did *Helicoprion* exist? How do we know?

- *Helicoprion* fossils are found in rocks from the Permian Era. Specifically they have been found in rocks ranging from 270-250 million years.

6: Karpinsky Makes the Call: *Helicoprion*

This chapter represents a turning point in *Helicoprion* research history when it is definitively given its own genus by Karpinsky.

What are some of the observations Karpinsky made by examining the Russian whorl fossils?

- Number of teeth on each whorl, smallest teeth at the center, p. 96.

Compare and contrast spiral patterns found in nature. How are they similar? How are they different? What other examples of natural spiral patterns can you think of?

- Nautiloids, ammonoids, forams, etcl, p. 97.

What does the name *Helicoprion* mean?

- From Greek, *helico* means "spiral" and *prion* means "saw", p. 98.

Why did Karpinsky classify the Russian and Australian fossils as different species of *Helicoprion*?

- Karpinsky determined that the two fossils were similar enough to be of the same genus, but different enough to represent two different species, p. 99.

What was Karpinsky able to learn about the fossils using polarized light microscopy (and what is it)?

- Polarized light microscopy uses polarized light to highlight different types of minerals in a thin sliver of a fossil under a microscope. Karpinsky identified vasodentin covered by

vitrodentin, which are found in both teeth and denticles. Karpinsky considered this to be evidence that the fossils were teeth, p. 99/100.

Why did Karpinsky admit what he didn't know in his paper?

- Karpinsky left the door open for other researchers to debate his claims and also continue research in other areas, p. 100.

How did the debate sparked by Karpinsky's paper help move scientific understanding about *Helicoprion* forward?

- Other researchers were inspired to prove Karpinsky wrong (or verify his findings) through their own studies, p.101-107.

7: A Shiver of Sharks

This chapter focuses on the aftermath of Karpinsky's turning-point paper and the importance of peer review and scientific argument in advancing scientific understanding.

Why did several new fossil specimens appear after Karpinsky's 1899 paper?

- Forgotten and misidentified specimens were found in museum collections, p. 109.

Why did Eastman determine that whorls were singular, rather than multiple, per animal?

- Eastman observed a fossil that included pavement teeth which appeared to work in concert with the single whorl, p.111/112.

Explain why Idaho yields more *Helicoprion* fossils than anywhere else in the world.

- Idaho was covered by a shallow, anoxic bay at the time when *Helicoprion* lived which provided a prime environment for fossilization, p. 115-117.

Explain how additional fossil specimens and various published papers following Karpinsky's 1889 paper led to the advance of understanding of *Helicoprion* (use specific examples).

- Karpinsky's 1889 paper inspired others to respond and research. As more fossil specimens emerged or were discovered, more papers were published, sparking more response. For example, Karpinsky's 1889 (and other) papers inspired Hay's research, which inspired further research and publication by Karpinsky (and even collaboration), p. 119.

What fossil evidence finally convinced scientists that they were looking at teeth, not fin spines of *Edestus*?

- A fossil was found that contained both the curved teeth, and also cranial (skull) material, p.120.

What evidence supported Hay's idea that each animal only had one set of blades, centered in their mouths?

- Bilateral symmetry, p.120.

Did the study of *Helicoprion* advance during World War I?

- During WWI scientists were pulled in different directions related to the war, not focused on research or ancient sharks, p.121-122.

8: Signs of Life

This chapter picks up with new fossil discoveries after over two decades without much movement on *Helicoprion* research. It introduces some initial discoveries (made using the tools available at the time) for certain fossils that become important later in the story.

What is a fossil mold?

- A mold is an impression of an actual fossil, p. 125.

How did *Helicoprion* fossils found in the Sierra Nevada (California and Nevada) help date the rock strata there?

- Because *Helicoprion* fossils had only been found in a relatively small window of the fossil record (between 270-260 million years ago) it was likely that the rock where these specimen were found were similar in age, p. 126.

What is a zone or indicator fossil?

- A zone or indicator fossil is found only at a very specific time in evolutionary history and the fossil record and so can be tied to this timeframe, p. 126.

What is a concretion?

- Usually round or oval rock formations that often form around an organic nucleus, p. 132.

What did Bendix-Almgreen discover about the fossil specimen named Idaho 4 that was special?

- Tessellated cartilage was preserved, p. 136.

What is tessellated cartilage?

- “A special type of cartilage in which tiny mineralized plates called “tesserae” form over parts of the cartilage in a mosaic held together by a mesh of connective tissue”, p. 137.

What did lack of strong wear marks on the tooth whorl fossils provide evidence for or against, according to Bendix-Almgreen’s observations?

- The whorl was not used for crushing crustaceans by the shark, p. 140.

9: The Art of Obsession

Focus in this chapter is on Ray Troll’s introduction to *Helicoprion* and how his role in the science, as a science illustrator and artist, began and progressed.

On page 144 artist Ray Troll’s writer friend told him, “if you can explain a concept to your bartender you’re a good writer.” What does that mean in terms of *Helicoprion*?

- Being able to explain scientific concepts in layman's terms both means that you understand the science yourself, and that you are able to communicate challenging concepts to the public.

Why are science illustrators important? Why is it important that they be up to speed on the latest research?

- P.146

Should science illustrators work as accurately as possible, or is it okay for them to incorporate their own style? Why or why not?

- P. 146

Discuss "artistic license" vs. scientific detail…

Scientist Rainer Zangerl told Ray Troll, "zee oldest teese are at the zee zenter of ze whorl." In your own words, explain how *Helicoprion's* tooth whorl grew.

- P. 148

How does Ray Troll's and scientists Zangerl and Bendix-Almgreen back and forth about Troll's drawings or *Helicoprion* fit into the process of science?

- P.151 and p. 157

Was the debate about how *Helicoprion's* tooth whorl fit into its head settled by the mid 1990's?

- No, p.154

Why was Ray Troll hesitant to listen to Richard Lund's scientific opinion about removing the gill slits on his *Helicoprion* drawing? What was the fossil evidence that Richard Lund used to support removing the gill slits from the drawing?

- Ray Troll felt that the gill slits made *Helicoprion* truly look like a shark. When the gill slits were removed it looked more like a ratfish - not nearly as sharklike or exciting. However, fossils of similar animals showed opercular covers, not gill slits, p. 155

<u>10: The New Guard</u>

Here the author introduces relatively recent research findings on *Helicoprion* from the early 2000's and kicks off the involvement of the Idaho team and their research.

Why did the arrangement of land on Earth during the Permian look so different from today?

- plate tectonics, P. 164

What fossil evidence did Lebedev find to determine how *Helicoprion* used its tooth whorl for feeding?

- scratch traces, P. 166

How did Lebedev reason between fossil evidence and the hypothesis that *Helicoprion* was a squid hunter?

- comparative anatomy, sperm whales, P. 166-167

What is taphonomy and how does it relate to Pruitt's study of *Helicoprion*?

- Pruitt thought the spiral may have formed in death, P. 188.

Why is important to conduct a thorough review the scientific literature about a topic before beginning new scientific research?

- P. 168-170 (also p.154)

Why were other scientists unhelpful/skeptical of Pruitt's interest in researching *Helicoprion* at first?

- Other scientists believed new fossil evidence was needed to progress the research, P. 170.

What were Pruitt's and Tapanila's backgrounds coming into the *Helicoprion* project? Did either of them set out to study *Helicoprion*?

- P. 167 and 171

What was Jesse Pruitt's original research goal in the *Helicoprion* research project?

- create a research database, P.174,

What did Pruitt and Tapanila discover about the 85th tooth on a *Helicoprion* tooth whorl?

- marked puberty, P.175.

What was important about Bendix-Almgreen's 1966 paper that was the key to moving Pruitt's research project forward?

- preserved jaw material, P.178.

<u>11: Resurrection, One Slice at a Time</u>

In this chapter we learn how CT scanning technology opened a new door into research about *Helicoprion*.

Why was the re-discovery of calcified cartilage by Jesse Pruitt in 2010 in the Idaho No. 4 fossil so important?

- Although it had been identified earlier by Bendix-Amgreen, new technology now existed to be able to "see" the cartilage jaw structure using CT scanning, p. 177-178.

What is CT scanning technology and how is it used in paleontology?

- CT scanning is computed tomography. Multiple x-rays are taken from different angles then assembled in a cross sectional image, p. 178.

Where did the money for CT scans of the *Helicoprion* fossil come from? Why?

- NSF grant to sort out chondrichthyan lineage for Tree of Life through ratfish scientist Dominique Didier in Pennsylvania, p. 182.

What did Pruitt and Schlader do for “proof of concept”?

- CT scanning at local hospital, p. 184.

How did Pruitt and Schlader create a 3-D computer model from the CT scan slices?

- P. 186

What role did Alan Pradel play when he was first brought into the project?

- Pradel was gifted at reading CT scans and helped identify jaw components on the CT scans, p. 189-191.

What new questions about *Helicoprion* did the new 3-D model bring up?

- P. 191, p. 194

Why did Ray Troll suggest that Pruitt, Schlader and Tapanila contact Cheryl Wilga, an expert on modern shark jaws?

- P. 194

<u>12: Coming to Terms</u>

How does the operation of human jaws compare to that of shark jaws?

- P. 199

How do scientists think jaws evolved?

- P.199

Explain the two theories of the evolution of teeth.

- P. 200-201

What is functional morphology?

- relationship of an organism’s anatomical form to its function, P.204

Why were Pruitt and Tapanila willing to share their data with Cheryl Wilga and Ramsay?

- It was to the benefit of the research and moving everyone’s understanding forward.

Explain examples of how Pruitt and Tapanila, Didier, Pradel, Wilga and Ramsey used the scientific practice of argument based upon evidence.

- P.206-207

Pradel wanted to focus on *Helicoprion’s* jaw suspension. Why did this worry Ray Troll?

- P. 209-211

13: To the Summit and Beyond

Team members from across the country and around the world meet in person for the first time to observe and discuss all the evidence and work towards publishing their findings.

Why was it important that the scientists working together to learn about *Helicoprion* meet in person?

- Everyone in the same place, same time, looking at fossils, scans, etc. bouncing ideas off each other.

What did each member of Team Helico at the Shark Summit in October 2012 bring to the table?

- P. 214-215

What was the goal of the Shark Summit?

- Publication, P. 215.

Summarize what conclusions the team came to about *Helicoprion* after all their collaboration and the two-day Shark Summit.

- P. 221-242

How many publications came out of the Shark Summit?

- Three papers, p. 220-221 (links on resource by chapter page).

14: Shark is a Verb

The nature of science is that although Team Helico's research and findings advanced our understanding, they also opened the door for other scientists to reinterpret or refute their ideas based on evidence.

Why is this chapter called "Shark is a Verb"?

- Our scientific understanding of *Helicoprion* is still changing with new evidence and new interpretation.

How is the process of science reflected in the author's quote about Team Helico's findings, "okay then, prove us wrong" on page 244?

- Science is an ongoing process of presenting ideas based on evidence while others identify flaws in those ideas and try to find their own evidence to support their thoughts.

Should Team Helico be annoyed that other scientists took exception to their findings?

- No, advancements in scientific understanding come from scientific debate, or argument. This is not unfriendly debate - but a constructive system to test and retest or examine and reexamine evidence to learn as much as we can from it based on different perspectives and understandings.

Does it matter if we know if *Helicoprion* had gill slits? Why or why not?

- While it may not matter to you personally to know whether or not a prehistoric shark did or did not have gill slits, this information is important to our larger collective understanding of evolutionary history on our planet. It is also important to the nature of science that scientists hold each other to standards of accuracy and base conclusions on evidence (not infer things that aren't represented by evidence).

What is necessary to definitively determine whether or not certain pieces of Ray Troll's most educated reconstructions of *Helicoprion* are accurate?

- New fossil evidence is required, P. 247-248

Do scientists know when and why *Helicoprion* went extinct? Why or why not?

- The fossil record indicates that *Helicoprion* went extinct prior to the larger extinction at the end of the Permian and that *Helicoprion* existed on Earth for about 10 million years. There is no clear indication in the fossil evidence yet discovered as to why *Helicoprion* went extinct, p. 250-251.