Next Generation Science Standards

The following two Performance Expectations align most closely with the content of *Resurrecting the Shark*. However, there are *many* correlations between additional Disciplinary Core Ideas, Science and Engineering Practices, Crosscutting Concepts, and Understandings about the Nature of Science outlined below.

Performance Expectation	Connection to *Resurrecting the Shark*
HS-ESS2-1. Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.]	The location, both globally and within rock strata, of *Helicoprion* and other fossils is directly tied to Earth's internal and surface processes across time and space.
HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]	The rise, existence and eventual extinction of *Helicoprion* (and other species) is related to factors within the environment. These cause and effect relationships can be studied through fossil evidence.

Disciplinary Core Ideas

NGSS DCI	**Concepts Addressed by NGSS DCI in Middle (when applicable) and High School (NGSS Appendix E)**	**Connection to *Resurrecting the Shark***
ESS1.C The	Rock strata and the fossil record can be used as	In chapter 2, some of the basic principles related to

history of planet Earth	evidence to organize the relative occurrence of major historical events in Earth's history. (Grades 6-8) The rock record resulting from tectonic and other geoscience processes as well as objects from the solar system can provide evidence of Earth's early history and the relative ages of major geologic formations. (Grades 9-12)	sedimentary geology, fossilization and fossil succession are addressed, as well as the history of the science behind our understanding of these concepts based on evidence. (see ESS2.B below) In chapter 5 the reader is taken on a tour of the fossil record, geologic time and evolutionary history through each time period and the life forms that define it.
ESS2.B Plate tectonics and large-scale system interactions	Plate tectonics is the unifying theory that explains movements of rocks at Earth's surface and geological history. Maps are used to display evidence of plate movement. (Grades 6-8)	The labeled map of Pangea, provides a visual reference for original location of fossil formation along a Permian seaway in relation to location where fossil are found now due to plate tectonics.
ESS2.E Biogeology	The biosphere and Earth's other systems have many interconnections that cause a continual coevolution of Earth's surface and life on it. (Grades 9-12)	The interaction between the biosphere and Earth's other systems plays a recurring role in this story - ranging from conditions ideal for preserving fossils, to human mining of fossil fuels leading to fossil discovery.
ESS3.A Natural Resources	Resources are distributed unevenly around the planet as a result of past geologic processes. (Grades 6-8) Resource availability has guided the development of human society and use of natural resources has associated costs, risks, and benefits. (Grades 9-12)	The fossils in this story, and the rock strata they are found within (often associated with fossil fuel resources such as coal), are located around the planet based on plate tectonics and the location of ancient seaways, conditions for fossil preservation and sedimentary rock formation, burial and eventual uplift and erosion. Extraction of fossil fuels (such as coal) have led to major breakthroughs in the science of geology and paleontology.
LS1.A	All living things are made up of cells. In organisms,	*Helicoprion* certainly had a specialized body structure

Structure and Function	cells work together to form tissues and organs that are specialized for particular body functions. (Grades 6-8)	with its unusual whorl of teeth. This story highlights the observation of fossil evidence to learn about the body placement and function of this structure.
LS1.D Information Processing	Each sense receptor responds to different inputs, transmitting them as signals that travel along nerve cells to the brain; The signals are then processed in the brain, resulting in immediate behavior or memories. (Grades 6-8)	Briefly mentioned are ampullae of lorenzini, specialized sensory receptors used by modern sharks to sense electricity and influence hunting behavior.
LS2.A Interdependent relationships in ecosystems	Ecosystems have carrying capacities resulting from biotic and abiotic factors. The fundamental tension between resource availability and organism populations affects the abundance of species in any given ecosystem. (Grades 9-12)	Extinction is a major theme of this book, including discussion of the five largest extinction events on our planet, as well as the extinction of species like *Helicoprion*. Resource availability is discussed as a possible factor in *Helicoprion* extinction.
LS2.C Ecosystem dynamics, functioning, and resilience	If a biological or physical disturbance to an ecosystem occurs, including one induced by human activity, the ecosystem may return to its more or less original state or become a very different ecosystem, depending on the complex set of interactions within the ecosystem. (Grades 9-12)	
LS4.A Evidence of common ancestry and diversity	The fossil record documents the existence, diversity, extinction, and change of many life forms and their environments through Earth's history. The fossil record and comparisons of anatomical similarities between organisms enables the inference of lines of evolutionary descent. (Grades 6-8) The ongoing branching that produces multiple lines of descent can be inferred by comparing DNA sequences, amino acid sequences, and anatomical and embryological evidence of different organisms.	This book is very rich in its deep dive into the fossil record - what it is, how it formed, the science behind it and how we can learn about past life on Earth through the fossil record. Focus is also strong on how rock and fossil evidence lead to our understanding of Earth's history. Comparative anatomy is explained and is addressed throughout the book in detail as scientists struggle to determine relationships between extant and extinct

	(Grades 9-12)	organisms based on fossil evidence. One of the main points of the research addressed by this book is to determine where in the Tree of Life *Helicoprion* fits in. Fossil evidence is compared to other fossil sharks and fishes, as well as with existing modern animals to classify *Helicoprion*. In chapter 5 the reader is taken on a tour of evolutionary history through each time period and the life forms that define it. Mass extinctions, their causes. and which life forms disappeared are explored. Faunal succession and the origin of our understanding of fossils and the fossil record are explored. The Principle of Superposition, an underlying understanding when comprehending the fossil record, is explained, as is the science as to how it was determined. Fossils are evidence of past life.
LS4.B Natural Selection	Natural selection occurs only if there is variation in the genes and traits between organisms in a population. Traits that positively affect survival can become more common in a population. (Grades 9-12)	*Helicoprion's* tooth whorl is an extremely specialized trait. Evidence from the fossil record indicates that these sharks survived for around 10 million years. This adaptation was successful over a long period until something happened that caused the sharks to die out.
LS4.C Adaptation	Evolution results primarily from genetic variation of individuals in a species, competition for resources,	*Helicoprion* evolved into a niche. Scientists in the book study the fossil evidence to try to better understand how

	and proliferation of organisms better able to survive and reproduce. Adaptation means that the distribution of traits in a population, as well as species expansion, emergence or extinction, can change when conditions change. (Grades 9-12)	*Helicoprion's* adaptations helped it to survive, and reasons that the sharks eventually died out. Competition for resources (or lack of resources - food) is explored as one reason for extinction.
LS4.D Biodiversity and Humans	Biodiversity is increased by formation of new species and reduced by extinction. Humans depend on biodiversity but also have adverse impacts on it. Sustaining biodiversity is essential to supporting life on Earth. (Grades 9-12)	This book explores the biodiversity of ancient Earth through the fossils that tell Earth's history. In working to determine where this particular shark fits into the picture, a diversity of ancient (and modern) creatures are brought up. The idea of extinction (and mass extinctions) is explored along with possible (non-human) causes.

Crosscutting Concepts

NGSS CCC	**Description (from NGSS Appendix G)**	**Connection to *Resurrecting the Shark***
Patterns	Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.	● Spiral patterns in nature (*Helicoprion's* tooth whorl, ammonites, ferns, galaxies, etc.) ● Classification systems (Linnaean taxonomy, cladograms) ● Locations where fossils are found (both worldwide and in which strata)
Cause and effect	Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.	● Mass extinctions ● Extinction of *Helicoprion* ● Locations where fossils are found (both worldwide and in which strata) ● Evolutionary cause for tooth whorl

Scale, proportion, and quantity	In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.	● Geologic time ● Relative time (e.g. *Helicoprion* lived before dinosaurs) ● Global distribution of rocks, fossils and plate tectonics (rocks and fossils formed when land masses and oceans were arranged differently than today) ● Time spans (*Helicoprion* survived for much longer than humans have existed) ● Uniformitarianism ● Evolution - slow change over generations
Structure and function	The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.	● Structure of *Helicoprion's* tooth whorl (single tooth, spiral) ● How tooth whorl fit within mouth ● Quest to understand function of this structure (teeth vs. fin spines vs. tail, etc.) ● Study of possible functions based on structure and where it existed in sharks body
Stability and change	For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.	● Mass extinctions and what caused them ● Extinction and what causes it ● Rock strata deposited over long periods of time ● Movement of Earth's plates ● Uniformitarianism ● Evolution - change over generations

Science and Engineering Practices

NGSS SEP (NGSS Appendix F)	**Connection to *Resurrecting the Shark***
Asking questions (for science) and defining problems (for engineering)	● Ray Troll's questions upon first seeing Helicoprion fossil ● Mr. Davis, Nicolay, mine workers, Karpinsky, Jessie Pruitt's questions upon first

	seeing Helicoprion fossil
Developing and using models	● Original sketches of fossils ● Photos of early fossils ● CT scans - digitized 3D images ● 3D printed model ● Bite force modelling?
Planning and carrying out investigations	● Jesse Pruitt worked with ? to come up with a research plan (measurement protocols, etc.) ● Karpinsky's systematic investigation ● Observing fossils ● Comparing fossil specimens
Analyzing and interpreting data	● Shark Summit ● Sharing of CT data with colleagues for input ● Jessie Pruitt piecing together 3D image data
Using mathematics and computational thinking	● Tapanila, Schlader, Ramsey use math to study fossils (e.g. spiral formula, bite force calculations) ● Scan data is digital representation of real fossil (computational thinking)
Constructing explanations (for science) and designing solutions (for engineering)	● Three published papers after Shark Summit ● Conclusions presented starting on Chapter 13, p. 221 ● Karpinsky's paper
Engaging in argument from evidence	● Disagreement and discussion among scientists from the start (e.g. fin spins vs. teeth, Lund and Grogan (and others) response to published papers) ● Ray Troll's "wanting" *Helicoprion* to look like a shark vs. ratfish (what does evidence show?)
Obtaining, evaluating, and communicating information	● Obtaining - literature reviews, reading papers by previous researchers, looking at fossils ● Evaluating - peer review, argument drives research (prove previous researcher is

	wrong) ● Communicating - published papers (Karpinsky, Bendix, participants in Summit, research since those papers), Ray Troll's art, photos, documentary film, *Resurrecting the Shark* book, reaching out to colleagues, social media (comments on articles online)

Understandings about the Nature of Science

NGSS Understandings	**High School**	**Connection to *Resurrecting the Shark***
Scientific Investigations Use a Variety of Methods	Science investigations use diverse methods and do not always use the same set of procedures to obtain data.	It is clear while following through the long and twisting story of *Helicoprion* that the scientific method is not a set of repeated steps like a recipe, but is a fluid and changing process across the time, space and many people.
	New technologies advance scientific knowledge.	New information about *Helicoprion* was gleaned from CT scan data and 3D modeling - not new fossil discoveries.
	Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings.	Scientists throughout the history of *Helicoprion* research embodied values of scientific inquiry.
	Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.	A variety of methods are used to investigate *Helicoprion* - including, for example, observation of fossils, modelling, and comparative anatomy.
Scientific Knowledge is Based on Empirical	Science knowledge is based on empirical evidence.	All knowledge about *Helicoprion* can be traced back to the fossil evidence, not guesses.
	Science disciplines share common rules of	Although different scientists involved in the long term study

Evidence	evidence used to evaluate explanations about natural systems.	of Helicoprion represented different areas and fields of science (geology, biology, paleontology, computer science) they all recognize the importance of evidence as a basis for scientific understanding.
Scientific Knowledge is Open to Revision in Light of New Evidence	Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	The debate about whether or not *Helicoprion* fossils were teeth or fin spines is an example of how scientific understanding may change and advanced based on new evidence and reinterpretation of existing evidence (e.g. observation of wear patterns confirming teeth vs. spines).
	Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.	There are many examples of scientific argumentation throughout *Helicoprion's* story.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	Laws are statements or descriptions of the relationships among observable phenomena.	Underlying principles in geology and paleontology such as the Principle of Superposition and Principle of Faunal Succession describe relationships between observable rocks and fossils that are consistent across time and space.
	Scientists often use hypotheses to develop and test theories and explanations.	Hypotheses are statements that drive research and arise from scientists asking questions about phenomena (e.g. Question: How was *Helicoprion's* tooth whorl situated in its mouth? Possible hypothesis: *Helicoprion's* tooth whorl was situated centrally in its bottom jaw. Scientists then present arguments as to why the evidence supports, or does not support, their hypothesis, based on their research findings.)
Science is a Way of Knowing	Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge.	The process of science was used over a long period of time and by many people to learn about *Helicoprion*. We can now relate scientific knowledge about *Helicoprion* based on these studies.

	Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.	The story of our understanding of *Helicoprion* demonstrates this well.
Scientific Knowledge Assumes an Order and Consistency in Natural Systems	Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future.	Uniformitarianism
Science is a Human Endeavor	Scientific knowledge is a result of human endeavor, imagination, and creativity.	Many people were involved in the scientific study of *Helicoprion* across time and space.
	Individuals and teams from many nations and cultures have contributed to science and to advances in engineering.	Many countries and nationalities are represented as contributors to the scientific understanding of Helicoprion (e.g. fossils were found in Australia, Russia and the U.S., people who contributed were English, Danis, Russian, American., and other nationalities.

Common Core Standards

English Language Arts

Science & Technical Subjects Grades 9-10	Science & Technical Subjects Grades 11-12
Key Ideas and Details: CCSS.ELA-LITERACY.RST.9-10.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.	Key Ideas and Details: CCSS.ELA-LITERACY.RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

CCSS.ELA-LITERACY.RST.9-10.2 Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.	CCSS.ELA-LITERACY.RST.11-12.2 Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
CCSS.ELA-LITERACY.RST.9-10.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.	CCSS.ELA-LITERACY.RST.11-12.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
Craft and Structure: CCSS.ELA-LITERACY.RST.9-10.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.	Craft and Structure: CCSS.ELA-LITERACY.RST.11-12.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
CCSS.ELA-LITERACY.RST.9-10.5 Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).	CCSS.ELA-LITERACY.RST.11-12.5 Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.
CCSS.ELA-LITERACY.RST.9-10.6 Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address.	CCSS.ELA-LITERACY.RST.11-12.6 Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.
Integration of Knowledge and Ideas: CCSS.ELA-LITERACY.RST.9-10.7	Integration of Knowledge and Ideas: CCSS.ELA-LITERACY.RST.11-12.7

Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
CCSS.ELA-LITERACY.RST.9-10.8 Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.	CCSS.ELA-LITERACY.RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
CCSS.ELA-LITERACY.RST.9-10.9 Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.	CCSS.ELA-LITERACY.RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Range of Reading and Level of Text Complexity: CCSS.ELA-LITERACY.RST.9-10.10 By the end of grade 10, read and comprehend science/technical texts in the grades 9-10 text complexity band independently and proficiently.	Range of Reading and Level of Text Complexity: CCSS.ELA-LITERACY.RST.11-12.10 By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

Mathematics

High School: Modeling