Euteleost Tree of Life – Web Module

Summative Evaluation Report

Submitted to:

University of Kansas

Submitted by:

Rockman et al
Independent · Insightful · Informative

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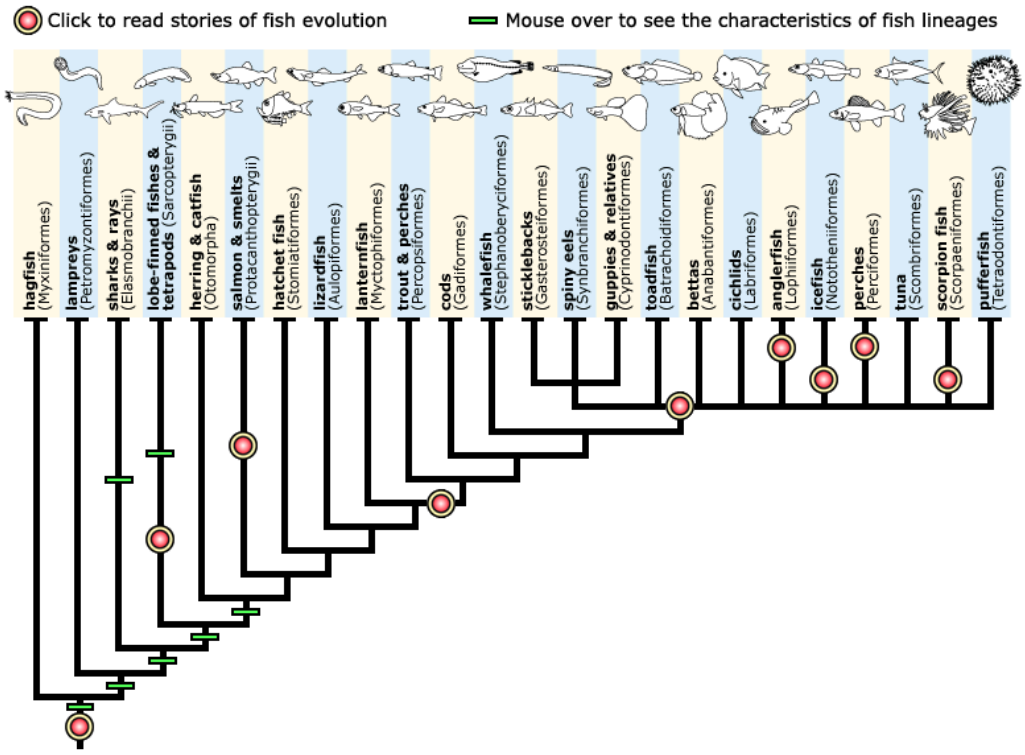
Introduction

Rockman et al (REA), a San Francisco-based research and evaluation firm, conducted an independent summative evaluation of the *Eutelelost Tree of Life: Web Module* (http://evolution.berkeley.edu/evolibrary/article/fishtree_01). The Euteleost Tree of Life (EToL) is a collaborative National Science Foundation research project between eight institutions, including Kansas University, to resolve evolutionary relationships within the euteleost fishes. The outreach component of this project is an interactive Web module that explores the science of fish and how fish are related to each other. The dissemination outlet for the module is the *Understanding Evolution* website – an evolution education website created by the University of California Museum of Paleontology (UCMP) and the National Center for Science Education.

The EToL Web Module consists of an interactive evolutionary tree (Figure 1) that focuses on relationships among the ray-finned fishes (Actinopterygii). It includes stories of fish evolutionary innovations and characteristics that evolved in different lineages.

Figure 1: Interactive Evolutionary Tree from the Web Module



The target audience for the Web module is high school aged youth. The main aim of the Web module is for users to explore the evolutionary history of fish and how they are related to one another. The specific educational objectives of the Web module are that

participants gain an understanding of: (1) some evolutionary innovations seen in fish, (2) shared traits, and (3) convergence (the tendency of unrelated animals to evolve superficially similar characteristics under similar environmental conditions.).

REA's summative evaluation was designed to (1) gather users' feedback about the website, as well as (2) assess the impact of the site on users' knowledge and attitudes about fish and fish evolution.

To meet these goals, evaluators recruited two groups of high school students to perform a series of tasks on the website and then provide feedback during a focus group discussion. The next two sections describe the study methodology and then background information about the participants. This is followed by a presentation of the study results and lastly a discussion of these findings, including recommendations.

Methodology

REA coordinated with a high school biology teacher to recruit ten of her students to participate in the study. All of the students attended a rural public high school in Sonoma County, San Francisco Bay Area. In May 2013, the evaluator met on separate days with two student groups afterschool at the high school. Group 1 consisted of three 9th graders and three 10th graders, and Group 2 had three 10th graders and one 11th grader (further information about participants is presented in the Participant Background Information section). REA obtained written parent consent and oral assent from the students. Each student participant received a $25 Amazon.com gift certificate for his or her participation, and the teacher received a $100 Amazon.com gift certificate for helping to recruit the students and coordinate the study.

The study session lasted approximately two hours and involved two phases. Phase 1 involved completing a background survey and Web module activities in the school computer lab, with each student working individually at a computer. Phase 2 was a focus group conducted in a classroom. Study procedures for each phase are detailed below. REA collaborated with project staff to develop the background survey, Web module tasks, and focus group protocol.

Phase 1: Background Survey & Web Module Activities

- Background Survey: Students completed a single-page background questionnaire, consisting mainly of fixed choice questions. Students provided information about the following: their age, grade level, gender, high school science classes, science class grades, online activity, and science knowledge and attitudes.
- Web Module Tasks: Each student received a packet with written instructions for performing a series of tasks with the EToL Web module, as well as space for taking notes and answering several questions. The evaluator read aloud the instructions,

kept track of time, and monitored student activity while each student worked individually at a computer. The instructions were as follows:

- Fish Stories Exploration:
  - *Spend 10 minutes exploring and reading about some of the "fish stories of evolution." When you are finished exploring (optional), use the space below to take notes about what you learned or what you thought of the stories.*
  - *Select the fish stories you visited, and circle the story that interested (or surprised) you the most.*
- Lineage/Branches Exploration:
  - *Spend 5 minutes exploring the "fish lineages" (or branches). When you are finished exploring (optional), use the space below to take notes about what you learned or what you thought of the lineages/branches.*
  - *Select the fish lineages (branches) that you explored, and circle the one that interested (or surprised) you the most.*
- Required Tasks: *Use the fish tree to complete the five tasks below to the best of your ability (15 minutes).* Note: See Table 1 for a listing of these tasks.
- Free Exploration: *When you have completed all the tasks, take a few minutes to explore the site further on your own.*
- Extra Tasks: *If you have extra time, use the fish tree to complete the three extra tasks below to the best of your ability.* [Note: See Table 1 for a listing of these tasks.]

Table 1 displays the eight Web tasks completed by students and corresponding correct answers. Due to time constraints, each group was required to complete five of these tasks, and if time permitted, they were to work on three extra tasks. In order to obtain feedback on all eight tasks, the required five tasks for each group varied. Both groups completed Tasks 1 and 2, while Group 1 completed Tasks 3-5 and Group 2 completed Tasks 6-8.

Table 1: Web Tasks

Task #	Web Task	Correct Answer	Group 1*	Group 2**
1	What is the name of the specific branch (or lineage) that led to tetrapods (four-limbed vertebrates that includes humans)?	Sarcopterygian	Yes	Yes
2	Identify two features shared by all fish.	Any two of the following: a. have a brain protected by a braincase and an obvious head region with eyes, teeth, and other sensory organs, b. gills, c. heart, d. hemoglobin in blood *Complex endocrine system, e. nerves that emerge directly from the brain (i.e., cranial nerves).	Yes	Yes
3	Identify the specific branch (or lineage) that has a unique type of scale called placoid and venom.	Chondrichthyes (sharks & rays)	Yes	Extra
4	How many lineages (or branches) independently evolved hermaphroditism?	Eight	Yes	Extra
5	Describe two characters or traits that are shared by all gnathostomes.	Any two of the following: a. upper and lower jaws, b. paired nostrils, c. series of gill arches, d. paired fins, e. horizontal semicircular ducts	Yes	Extra
6	Identify the specific branch or lineage that has evolved tubular eyes, bioluminescence, AND hermaphroditism.	Lizardfish (Aulopiformes)	Extra	Yes
7	Name two specific branches (or lineages) that are part of a polytomy on this tree?	Any two within either of the following lists: a. sticklebacks, spiny eels, guppies & relatives; b. toadfish, betas, cichlids, anglerfish, icefish, perches, tuna, scorpion fish, pufferfish	Extra	Yes
8	Identify one character/trait that would allow you to distinguish a herring from a pufferfish?	Any of the following: a. single dorsal fin; b. diamond-shaped body scales that articulate with each other via a special "peg and socket" system; c. endoskeleton and fin muscles that do not extend far into the paired fins; d. elongated, flexible fin rays that form a fin	Extra	Yes

*Group 1 was required to complete Tasks 1-5 and only work on Tasks 6-8 if they had extra time.
**Group 2 was required to complete Tasks 1-2 and 6-8 and only work on Tasks 3-5 if they had extra time.

Phase 2: Focus Group Discussion

REA used a focus group protocol comprised of five sections for each group discussion. The purpose of each protocol section is presented below along with questions and prompts:

- A. Introduction: Provide an overview of the discussion, and give instructions for the focus group.
- B. Background questions: Gather information about participants' attitudes about biology, use of the Web for science topics, and previous knowledge and experience with evolutionary tree diagrams.
- C. Feedback about the Module: Examine participants' reactions to the Web module. Questions included:
    - What was your overall impression of the Web module?
    - How would you describe it to a friend?
    - What did you like most and least about it?
    - How easy was it to understand the content?
    - What did you think of the site's navigation?
- D. Impacts: Gather information about how the Web module influences the participants in terms of their learning and attitudes about fish and biology. Questions included:
    - What did you learn from the Web module?
    - What was one thing that surprised you about fish?
    - Did your interactions with the module affect how you feel about biology/science/fish? If so, how?
- E. Other Feedback: Go over the correct answers to the tasks, and ask participants for their feedback about the tasks. Collect suggestions for improvements and whether participants would revisit the module in the future. Questions included:
    - Were you able to complete everything on your task list? Which tasks did you find difficult? Describe.
    - What are you suggestions for making the Web module better?
    - Do you want to visit this module again? Why or why?

For the Web module activities, REA scored task responses as correct or incorrect. REA audio-recorded and then transcribed the focus group discussions. For the majority of the open-ended data (i.e., the notes portions of the Web module interaction and the focus group discussion), REA analyzed responses for trends. The most common themes are presented in this report.

Participant Background Information

We present background information about the ten participants in the following three sections: (1) Demographics, (2) Prior Science & Biology Performance and Attitudes, and (3) Prior Evolutionary Tree Knowledge.

Demographics

Students (n = 10) self reported demographic information about their gender, age, grade level, and typical online activity. Six female and four male students participated. Three of the participants were 9th graders, six were 10th graders and one was an 11th grader. The average participant age was 15, with participants ranging from 14 to 16 years old. Regarding daily Internet use, students spent between one to five hours online each day. Specifically, four participants spent 2 hours or less online daily, three participants spent 3 hours online daily, and four participants spent 4 hours or more online daily. Students did not typically go online to find out about science topics, unless required to for school, and could not name specific science sites that they had used in the past.

Prior Science Performance and Attitudes

At the time of the study, the 9th graders were taking Biology, the 10th graders were taking Earth Science (and had previously taken Biology), and the 11th grader was taking AP Biology (and had previous taken both Biology and Earth Science). These students reported typically earning grades of A's (n=4), B's (n=6), or C's (n=4) in their science classes. (Note: Students could select multiple grades, so the total n does not equal the number of participants. Specifically, the breakdown of grade responses by participant is as follows: A's: n=2; A's & B's: n=2; B's: n=2; B's & C's: n=1; C's: n=2; B's, C's, & D's: n=1)

Overall, students' attitudes about biology and science in general were positive (See Table 2). Six participants agreed that they were good at science, eight were interested in biology, and only three participants found biology to be difficult.

Table 2: Background Survey – Agreement Items

Rate your level of agreement with each statement.		**Number of Respondents**				
	Median*	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I am good at science.	4.0	0	0	4	5	1
I am interested in biology.	4.0	0	0	2	5	3
I find biology to be difficult.	2.5	1	4	2	3	0

*Scale: 1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree.

During the focus group discussion, the evaluator asked students to share their feelings about biology. As evidenced in the attitudinal items, most students reported positive feelings about biology, describing it as enjoyable and interesting. Example comments were:

> *Biology is one of my favorite subjects.*
>
> *I really like biology, especially marine biology. It's a career that I am looking at.*
>
> *Biology is a fun subject. I like biology because learning the structure of life is a really interesting subject and learning the building blocks of matter and how people have evolutionized is really interesting.*
>
> *I like learning more about life.*
>
> *I'm interested in the characteristics of animals and planet life.*

Several participants, however, expressed a preference for certain biology topics over others based on interest or perceived difficulty. Example comments included:

> *I like some parts of biology…I don't like genetic probability…Punnett squares.*
>
> *Some things I like learning about more than others – some are more interesting than others. Drugs, alcohol, and evolution are interesting – how it affects you and everything.*
>
> *I like biology. Some units are harder than others, but some are easy.*

Prior Evolutionary Tree Knowledge

When selecting students for the study, REA provided the teacher with the following prerequisite knowledge about evolutionary trees (as specified by project staff) for students to be able to take part in the study.

> *[Students] should be able to read and interpret the basic structure of a tree – e.g., understand that the branching pattern depicts evolutionary relatedness, can identify different lineages and its closest relative by using the branching pattern, can identify shared and distinct characters of different lineages using the tree, and understand the concept of monophyly (common descent from one source/ancestor).*

The teacher assured REA that she selected student participants who met these criteria, commenting that the participants were "good with the previous exposure to evolutionary trees." However, when we directly asked students about their background knowledge about evolutionary trees (both at the beginning of the study and during the focus group),

students self reported less familiarity with evolutionary trees than described by the teacher. On a scale of 1-5 (1: not familiar at all to 5: very familiar), three participants noted that they were not familiar at all with evolutionary tree diagrams (rating of a 1), and the remaining students had only slightly more familiarity (rating of a 2: n=3; rating of a 3: n=4). In addition, prior to the study, only three of the ten participants knew what the term "lineage" meant. Although all participants had completed a lesson in their biology class on whale genetics involving evolutionary trees, some students either did not remember much about the lesson or did not remember it at all. For example, one participant said, "It's in the back of my mind somewhere." Those who remembered the lesson described it as follows:

> *We did something about the evolution of sperm whales this year in biology…looking at different and similar characteristics between certain animals.*
>
> *A peccary, a giraffe, there were a bunch of different animals…which shared the same design in their skeletal systems…We were comparing their DNA sequences to each other and had to find how similar they were…It was freaky and weird how similar they were. How much they matched up…Who would have known that a rhino was related to a whale that closely?*

When asked to specify what they knew about evolutionary trees and specifically what tree diagrams show, only a couple of students responded, expressing uncertainty about their answers and providing basic responses. Example responses include:

> *[Evolutionary trees] show the different characteristics that were passed on to different generations.*
>
> *[Evolutionary trees] show the ancestors. How they were before they evolved.*
>
> *[The branching pattern of the tree shows] the linked connections…which ones shared a common ancestor.*

Findings

We present the data in three sections below: Knowledge, Attitudes, and Feedback. When relevant, we organize findings by sub-topics within these sections. In the Knowledge section, we relay findings about participant performance on the eight module tasks, followed by findings about participant self-reported learning (e.g., about what a "fish" is and about traits that evolved in various fish lineages). In the Attitudes section, we present limited findings about the influence of the module on participants' feelings about science, biology, or fish. In the Feedback section, we provide overall participant feedback, as well as feedback about specific portions of the module (i.e., Fish Stories and Lineages), navigation, and comprehension. We also include participant recommendations for improvements to the module, including suggestions specifically regarding content presentation and for additional content. Across sections, we have included extensive participant quotes in order to provide rich data for project staff.

Knowledge

Within this section, we organize findings about knowledge by two main subtopics: Task Performance and Self-Reported Learning. Within the Task Performance section, we provide an overview of participant performance (correct or incorrect) across the eight module tasks. Details about participants' answers and feedback for each of the eight tasks are in Appendix A. Within the Self-Reported Learning section, we present a summary of learning reported by participants, according to four topics and sections: (1) Fish Evolution & Evolutionary Trees, (2) What Is a Fish? (e.g., characteristics or guidelines for determining whether an animal is a fish or not), (3) Traits that Evolved in Various Lineages (e.g., hermaphroditism and (4) Traits Common to a Specific Lineage.

In terms of participant task performance and learning from the module, an overview of findings is as follows. Participants:

- Were often unsure of their answers for the tasks, answering tasks correctly on average 56% of the time.
- Performed best on Tasks 2, 3, and 7 (over 70% of participants responding correctly) and worst on Tasks 6 and 8 (with 20% or less of participants responding correctly).
- Learned more about what a "fish" is (i.e., the characteristics or guidelines for determining whether or not an animal is a fish and exceptions to those guidelines), as well as about previously unfamiliar species of fish (e.g., barreleye fish).
- Learned about traits that evolved in various fish lineages. Specifically, participants learned that some fishes could change sex or be a hermaphrodite; about species of venomous fish and the evolution of venom in fish; about fish with tubular eyes; that some fish have antifreeze; and about the anglerfish (which has bioluminescence).
- Gained familiarity with traits common to specific fish lineages.
- Expanded upon previous learning about evolution and natural selection by learning more about how fish evolved and different lineages emerged.

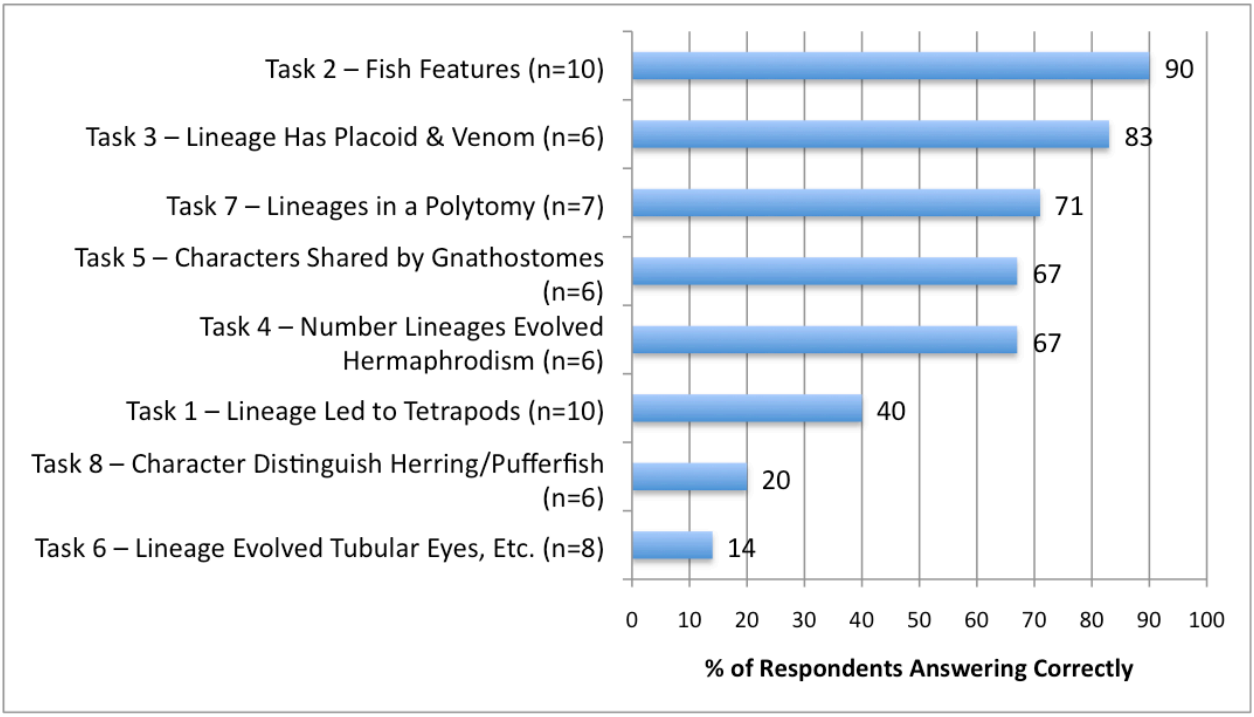
Task Performance

During the allotted fifteen minutes for the module tasks, most of the participants (n=6) completed only the required five tasks, however four also attempted one or more of the three extra tasks. (Refer back to Table 1 for a listing of the required and extra tasks for each of the two groups.) Participants relayed that they had adequate time to complete the required tasks, though several noted that they did not finish or had to guess due to the difficulty level of some the tasks and not being able to find the answer. Several students (including one who was among the highest performing on the tasks) expressed that they did not feel confident in or were unsure of their answers. Example comments include:

> *I finished, but I couldn't find some of [the answers].*
>
> *I didn't finish it either – well, I did, but I guessed.*
>
> *I didn't feel 100% on any of my answers.*
>
> *I failed.*
>
> *[The module] was informational, but when we had to do the tasks, it was really confusing.*

On average, the participants answered the tasks correctly 56% of the time. The lowest performing student answered only one of five tasks correctly (20% correct), while the highest performing student correctly answered all six tasks that he attempted (100% correct). Student task performance did not significantly correlate with the background questions about science grades or familiarity with evolutionary trees. Figure 2 displays overall participant performance for each of the eight tasks. Participants performed best on Tasks 2 (Fish Features), 3 (Lineage has Placoid and Venom), and 7 (Lineages in a Polytomy) with over 70% of participants responding correctly. Participants performed worst on Tasks 6 (Lineage Evolved Tubular Eyes, Etc.) and 8 (Character Distinguish Herring/Pufferfish) with 20% or less of participants responding correctly. More data is needed to fully understand why some tasks were easier for participants than others. However, Tasks 6 and 8 both seemingly required an in-depth reading and understanding of the tree and/or the module – Task 6 required participants to compare trees on three different pages of the site, and Task 8 required participants to identify a lineage and use it to discern traits for two different fishes.

Figure 2: Percentage of Respondents Answering Correctly by Task



See Appendix A for a full listing of participants' answers (correct and incorrect) and feedback for each of the eight tasks.

Self-Reported Learning

In the focus group and through their note-taking during the module tasks, students described what they had learned from the Web module. Overall, participants learned about the evolution of fish, what a "fish" is (e.g., characteristics or guidelines for determining whether an animal is a fish or not), traits that evolved in multiple lineages (e.g., hermaphroditism and venom), and traits common to a specific lineage.

We organize and present findings regarding participant learning using the following four sections: (1) Fish Evolution & Evolutionary Trees, (2) What Is a Fish?, (3) Traits that Evolved in Various Lineages, and (4) Traits Common to a Specific Lineage. The Traits that Evolved in Various Lineages section contains five subsections, each about participant learning for a trait that evolved in various lineages and that was presented in a specific Fish Story:

- Gender (from the Gender-bending Fish story),
- Venom (from the Oh Fish, Where is They Sting? story),
- Tubular Eyes (from the Googly-Eyed Fishes story),
- Antifreeze (from the No Ice in Their Veins story), and
- Bioluminescence (from the A Light in the Darkness story).

Fish Evolution & Evolutionary Trees

Several participants said that the Web module reinforced and expanded upon their previous learning about evolution and natural selection, showing how fish evolved and different lineages emerged with different characteristics. Comments included:

> *[From the module, I learned] the basic evolution of fish. All fish share a common ancestor and some characteristics were passed down to different generations. From those different generations, they passed on those characteristics, and different species of fish branched off from them. I sort of had that information before, but it's really explanatory and reinforced in this [site]. It really sets it in…If I ever had to do some research on generations of fish, this site's where to go.*

> *[The module] reinforces those basic things that you learn about evolution and natural selection and the divisions of different species from one common ancestor…It shows the break down of evolution and how they branched off.*

> *I knew some of the stuff they talked about already, but it did explain it more. There was a story about natural selection. I did get some of it [already], but when I read the [story] I was like, "Oh, this is how this happens." It explained it a little bit more.*

> *I learned how some fishes have changed over time…[I learned the term] lineages…I learned how all types of similar fish that descended from others are alike…what they have in common.*

One participant, who said that she had not used an evolutionary tree before, noted that she learned about evolutionary trees from interacting with the module.

What is a Fish?

Participants learned more about the category "fish" (i.e., what is a fish) after exploring the Web module. For example, they were surprised to learn that the number of different species of fishes was so large (i.e., 27,900).

> *There are more than 27,900 species of fish. Wow!...We get our large number of diverse fish from different traits that were passed on.*

> *There are a lot of fish.*

> *I learned more about the qualities and traits of fish. I knew what they looked like. I know them, but I don't KNOW them.*

Participants frequently mentioned learning about the characteristics that all or most fishes share, such as that all fishes have a brain protected by a braincase. A few participants also

noted that they learned that "fish" is a convenient term used to refer to diverse aquatic organisms.

> *All fish have a brain inside a braincase. I didn't know that was a certain requirement for all fish.*

In addition to learning the guidelines for determining whether an animal is fish or not, participants also learned about some of the exceptions to these guidelines. For example, several participants noted how surprised they were to find out that a fish could have lungs or live outside of water. Comments included:

> *I didn't know…there are guidelines for a fish being a fish, but there are certain cases where they just don't fit those guidelines…not all fish follow the "guidelines" that most fish meet.*

> *Fish usually breathe through their gills, but I didn't know that they could have lungs like us and still be in water.*

> *I didn't know that there were fish that had types of lungs.*

> *And, it says, "Most fishes live in water…and I was like, "Wait a minute. I thought all fish lived in water."*

Traits that Evolved in Various Lineages

Participants most frequently expressed learning from one or more of the five Fish Stories that focused on specific traits that evolved in various lineages (i.e., Gender-bending Fish; Oh Fish, Where is Thy Sting?; Googly-Eyed Fishes; A Light in the Darkness; No Ice in Their Veins). While participants learned about specific traits (e.g., hermaphroditism) or previously unfamiliar specie(s) of fish (e.g., stonefish and barreleye fish), they did not typically draw this learning back to the evolutionary tree (e.g., that or how these traits evolved in various lineages).

> *I'd never heard of the lizardfish. I hadn't heard about most of those fishes.*

Below, we present a summary of participant learning about each of these five traits that evolved in various lineages: gender, venom, tubular eyes, antifreeze, and bioluminescence.

Gender (from the Gender-bending Fish story)

Participants were often interested in and surprised to learn (from the Gender-bending Fish story) that some fishes could change sex or be a hermaphrodite. They also noted that they learned the meaning of the term hermaphrodite. Comments about learning regarding gender concepts included:

I learned that some fishes can be hermaphrodites, which means they can have both male and female reproductive organs...They can start male or female and later in their life change to the opposite gender…I never knew it could be a male, and then it could be a female…or a female and then a male.

Something I learned and that interested me was that a hermaphrodite is an organism that has both male and female reproductive organs and can perform on both male and female parts.

I learned about the clown fish…that it is a hermaphrodite…that it could be a boy and girl. I instantly thought of Nemo.

[I learned the term (protandry) for] when a fish starts as a male and turns to a female and vice versa.

Venom (from the Oh Fish, Where is They Sting? story)

Several participants also remarked about learning about the number of species of venomous fish, specific species of venomous fish (such as the stonefish), and about the evolution of venom in fish:

There are some things that I didn't know, and then once I clicked on it, it told me about it…I was surprised about] all the species that there are of venomous fish…I knew there were venomous fish, but I didn't know there were over 100's of species…The most common venomous fish is the stonefish because people can't see it and step on its spines...The ray-finned fish causes about 50,000 reported injuries.

The stonefish…it disguises as rock/coral and releases spines full of venom.

Venom has evolved multiple times in fish.

Tubular Eyes (from the Googly-Eyed Fishes story)

Two participants noted that they learned about fish with tubular eyes (i.e., about barreleye fish or about different species of fish with tubular eyes):

I learned about barreleye fish. I'd never heard of googly-eyed fish.

Salmon & smelts, lizardfish, whalefish all evolved tubular eyes.

Antifreeze (from the No Ice in Their Veins story)

Two participants noted that they learned that some fish have antifreeze in order to be able to survive in waters with very, very cold temperatures:

I learned that the fish have an antifreeze agent in their blood that suppresses ice crystals from forming.

There was a story for me that really popped out…It was something involving ice and fish. That was pretty interesting because I didn't know that fishes live in cold, cold water.

Bioluminescence (from the A Light in the Darkness story)

One participant mentioned that she learned about the anglerfish, which has bioluminescence.

I liked the glow-in-the dark fish…the anglerfish.

Additionally, another participant noted that she had learned about the different oceanic zones from the Light in the Darkness story.

Traits Common to a Specific Lineage

During the focus group, only several participants commented about learning about traits common to a specific lineage. They did so by interacting with the scroll-over lineages on the evolutionary fish tree. Comments included:

The green things [lineages] showed you the characteristics that they have in common. I didn't know some of that stuff…It's kind of cool to see what they all have in common, though.

I learned how closely related some fish are to each other. Like the structures and characteristics that some have – like diamond-shaped scales and others have rough scales.

The scientific or lineage name, I did not know [before interacting with the site].

When taking notes when interacting with the lineages, two or three participants wrote down traits of each of these four fish lineages: osteichthyes, actinopterygii, chondrichthyes, and sarcopterygii. (Note: Participants did not choose to write notes for the craniata, vertebrata, or gnathostomata lineages.) Example student notes for each are:

Osteichthyes have bony skeleton, pair of lungs, or a swim bladder that evolve lungs, bony fin rays.

Descendants from the actinopterygii have inherited a single dorsal fin, diamond shaped body scales, endoskeleton, flexible fin rays.

Sharks and rays descended from chondrichthyes and they have internal skeleton, unique types of scales, fin rays.

All organisms descended from this ancestor are sarcoptergyians – they all inherited the following traits, which are fins (limbs).

Attitudes

While our findings indicated that participants gained knowledge about fish from the Web module, most of the evidence suggested that the module did not influence participants' attitudes about science, biology, or fish. Comments included:

No [it did not affect my attitudes about fish], [the module] just tells us more about fish.

I'm still not interested in fish.

Still, one participant noted that he gained a greater appreciation for fish from the site, specifically due to their ability to adapt and survive over time and in wide variety of environments:

I think fish are pretty awesome…they are pretty awesome creatures. They deserve a little bit of respect. I feel like I got that from the site. There are some fish that I don't know how they survive. You have a carp, and it's just there. Then you have fish that can survive in -40 degrees and they can live…[Fishes] are pretty durable creatures. Fishes have been around since [a long time ago]. They've always been able to adapt to whatever situation they've been in.

Feedback

Within this section, we organize participant feedback by seven subtopics: 1) Overall Feedback, 2) Fish Stories, 3) Fish Lineages, 4) Navigation, 5) Comprehension, 6) Content Presentation Suggestions, and 7) Suggestions for Additional Content. In the Overall Feedback subtopic, we detail what participants liked most and least about the site in general. In the next two subtopics – Fish Stories and Fish Lineages – we present an overview of which stories and lineages they explored and which they liked most. We then share participants' reactions to their attempts to navigate and understand the information in the module in the Navigation and Comprehension subtopics respectively. When applicable, we incorporate participants' suggestions for improvements into each of the first five subtopics. In the final two subtopics, we present participant recommendations specific to areas not previously discussed: Content Presentation Suggestions and Suggestions for Additional Content.

In terms of positive participant feedback about the module, an overview of highlights is as follows. Participants:

- Appreciated the quality of the information provided on the module, describing it as solid and informative;
- Particularly enjoyed the Fish Stories, often selecting a story that focused on specific characters that evolved in various lineages as their favorite site element (e.g., Googly-Eyed Fishes and Gender-Bending Fishes) or expressing an interest in learning more information about a particular fish mentioned in the module;
- Most frequently cited the craniata and sarcoptergii lineages as the most interesting and/or surprisingly lineages in the module;
- Described the module navigation as clear and frequently noted that the dynamic scroll-over effects on the homepage (for the lineage and Fish Story icons) were among their favorite elements of the site;
- Indicated that the module content was largely understandable but also provided a variety of suggestions on how to improve its comprehensibility (e.g., adding pronunciation information or additional term definitions).

Overall Feedback

On the whole, participants liked the site – on a scale of 1-5 (1: didn't like it at all to 5: liked it very much), they rated the site 3.9 on average (rating of 5: n=3, rating of 4: n=3, rating of 3: n=3, and rating of 2.5: n=1). What participants liked most about the module was the quality and amount of information provided.

> *[What I liked most about the site was] the quality of the information….If you need to get your research done, this can get the job done.*
>
> *Solid information…it's useful.*
>
> *I liked the information, and I like how it had a diagram of the fish.*

Participants largely reported that the Fish Stories were the most engaging portion of the module. They often mentioned a particular story as their favorite site element (see the section below for more details) or expressed interest in learning more information about a particular fish mentioned on the site.

> *The stories were great and interesting.*
>
> *[The tree] seems bland but the fish stories caught my attention.*
>
> *I clicked on the fish that interested me. So pretty much every fish I clicked on, I was like, "That's cool."*

Participants, however, felt that the module was not particularly appealing or engaging visually. For example, they noted the lack of color in the module. They also rated the site a 2.5 on average on a five-point scale in terms of how engaging it was (1: not engaging at all to 5: very engaging). (Note: The breakdown of engagement ratings by participant is as follows: rating of a 3: n=6, rating of a 2: n=3, rating of a 1: n=1). To increase engagement, students suggested adding more color and pictures to the module, particularly on the homepage. Example comments included:

> *I'd want to give it a 5, but I'm going to give it a 4…I really do like the site and I think it's really informative and you learn a lot, but you want something that's going to pop a little more and catch the reader's eyes, [so they think,] "Oh that looks pretty cool, I want to check that out." It doesn't have that pop that a lot of people are looking for when it comes to websites nowadays. You go on National Geographic, and it's 3D images and crazy colors and pictures…[On the module, you could] blow it up a little more and give it some color and more details of the fish…If you look at it right now, it's just black outlines. A little more texture would really make it pop.*
>
> *It gives lots of information about fish and stuff – that's the good part about it. But, maybe they should make it more exciting – like a color background.*
>
> *[The module was] boring in terms of how it looked, but the information was pretty interesting.*
>
> *Especially because it's [geared] towards teens…A lot of them would look at this and feel like, "Oh, we have to do this." They wouldn't just go there because they wanted to. They'd go on there because they had to.*
>
> *If I looked at this, I don't know what I would want to change, but I wouldn't be like, "Oh. This is what I want to read."*
>
> *[It needs to be] more exciting…colors…bigger pictures.*

In terms of future use of the module, participants considered the module mainly a resource for school projects, noting that they would revisit the site if required, but not out of their own interest or desire.

> *I'd only visit it for school.*
>
> *If I didn't have to…if I wasn't doing this study [if it wasn't an assignment], I probably would have never gone to it.*

Fish Stories

During the ten minutes of allotted time for exploring the Fish Stories, students chose which stories they wanted to read and then selected a story that they found most interesting or surprising. Out of the nine Fish Stories in the module, participants visited three of the stories on average, and ranged from one to six stories visited. Table 3 provides an overview of the number of participants who visited and selected each story as their favorite. Students were most frequently drawn to the What is a Fish? and A Light in the Darkness stories (n=5). They most often (n=2 for each) selected the Googly-Eyed Fishes or Gender-Bending Fish stories as the most interesting and/or surprising story. However, there was not a clear favorite story among the students, since they selected a range of stories. Students were seemingly least interested in the two stories that focused on how to read or interpret an evolutionary tree (Percomorphs and Polytomies; Fish on Equal Footing) – no students selected these stories as their favorite and they were among the least visited stories.

Table 3: Overview of Fish Stories Visited & Considered Most Interesting/Surprising

	Number of Respondents (Total n=10)	
Fish Story	**Visited***	**Favorite****
What is a Fish?	5	1
A Light in the Darkness	5	1
Oh Fish, Where is They Sting?	4	1
From Water to Land	4	0
Googly-Eyed Fishes	3	2
Gender-Bending Fish	3	2
No Ice in Their Veins	3	1
Percomorphs and Polytomies	3	0
Fish on Equal Footing	1	0

*Participants could visit more than one story, so the total n does not equal the number of participants.
**The one story that a participant considered most interesting or surprising. Note: two out of the ten students did not specify a favorite.

Comments about their favorite stories included:

My favorite story was the Googly Eyed one. I thought that was really cool.

I like the clownfish – the Gender Bending story – because they can mate…at one time they can be a male, and then later in their life, they can be a female…I think that's cool!

> *My favorite story was the scorpion fish [Oh Fish, Where is Thy Sting?] because it told me information about the different venomous fish.*

Only a few participants had time to freely explore the module after finishing the required tasks, and those who did, spent this free exploration time visiting the fish stories that they had not yet visited. Comments included:

> *After I did the tasks, I went to the different stories that I hadn't read and skimmed through them and tried to see different information that I didn't know.*

> *I looked at the diagram of the fish in the What is a Fish? story. I thought it was cool, because I think fish are so cute. To be honest, I didn't know that they had a kidney and all that stuff because they are so little and small.*

One participant suggested making the Fish Stories stand out even more on the site to draw users to them, since she felt that the stories were the most informative portion of the module:

> *When it said about the "Fish Stories" [on the homepage], I wish it were more drawing to the "Fish Stories." At first, I didn't understand "Fish Stories", but once you actually clicked on it, it was pretty cool…so, maybe if it advertised "Fish Stories" better, then you'd be more willing to click on them.*

Fish Lineages

Similar to the Fish Story exploration, students decided which lineages they wanted to explore during a five-minute period, and at the end, selected the lineage that they found most interesting or surprising. Four participants explored all seven lineages; three participants explored only three lineages; and the remaining three participants explore two lineages or less.

Table 4 provides an overview of the number of participants who explored and selected each lineage as their favorite. In summary, students were most frequently drawn to the two vertical lineages: chondrichthyes (n=8) and sarcopterygii (n=7), and visited the other lineages fairly equally in terms of frequency (n=5 or 6). In addition, they most commonly found either the craniata or sarcopterygii lineage to be the most interesting and/or surprising lineage (n=4 vs. n=3, respectively).

Table 4: Overview of Fish Lineages Explored & Considered Most Interesting/Surprising

Fish Lineage	Number of Respondents (Total n=10)	
	Explored*	Favorite**
Chondrichthyes	8	1
Sarcopterygii	7	3
Craniata	6	4
Vertebrata	5	0
Gnathostomata	5	0
Osteichthyes	5	1
Actinopterygii	5	0

*Participants could explore more than one lineage, so the total n does not equal the number of participants.
**The one lineage that a participant considered most interesting or surprising. Note: one out of the ten students did not specify a favorite.

Navigation

Participants described the module's navigation as clear, and they frequently said that the dynamic scroll-over effects on the homepage (for the green lineage icons and red Fish Story icons) were among their favorite elements of the site. Participants found these interactive scroll-over elements helpful because they provided a preview of information in the Fish Stories, and for the lineages, they provided extra information without users needing to open a new page or window. Example comments about navigation included:

> *I adore the highlighting effect. Not only does a text box pop up and explain each lineage, but it highlights all branches that apply. The key above is self-explanatory. No issues here.*

> *I like that when you click on the lineages, a little side bar pops up instead of going to another window…I like that you can just look and not have to go into a different window to read it…So then, when you want to look at another one, you don't have to go all the way back and do it again. In this case, it's just right there.*

> *I like how the little red dots [for the Fish Stories]…when you click on it, something pops up to tell you what it is or what you are going to read about...it gives you a brief outline of what it is gong to be…I [also] liked the little green things [lineages] because they showed you which [fishes] have what…when you get close to them, it popped out…I think that's cool.*

> *It was easy. Once you got close to the thing, it showed you what it was about.*

The most common critique about navigation was that the scroll-over effects would sometimes freeze, requiring participants to refresh the page in order for the effects to work again. Evaluators also experienced similar freezing problems for the module. Participant comments regarding the freezing of the scroll-over effects included:

> *Yes. It was sticking every two seconds.*
>
> *[I had to reload the page.] It may be a programming problem of the site.*

One participant struggled with navigating the module and suggested that the lineage and story icons on the homepage be further apart to avoid confusion:

> *For me, [the navigation] was pretty hard. The green lines were close to the stories. So, I would try to click on the green line [lineage], and it would take me to the story instead. They were too close together.*

Comprehension

Although the majority of participants reported to understand the module content, there was mixed feedback about how easy it was to understand. Those who did understand it made comments such as:

> *I liked the content. It was basically understandable. It was interesting.*
>
> *The lineages were pretty easy to understand...I like the descriptions of the various lineages/branches.*

Those who had a harder time with the content most often noted that the site contained long or complex terms, such as the lineage names or species names, that were not defined, broken down, or sufficiently explained. Additionally, the module did not provide users with information regarding pronunciation of these terms. One participant noted that, due to these factors, the site appeared to be geared more towards experts than teens: "Sometimes I feel like it is dedicated to people who know more about fish, with the sense that they didn't define things…how the words were pronounced or the definitions."

Participants provided the following four themes of suggestions on how to increase comprehension of the module content. Example quotes are provided after themes.

1. Help readers to feel more comfortable with the Latin or longer words in the module by including definitions and pronunciations. If possible, present these tools on the same page as the terms, instead of requiring users to open a new browser window.

> *There were really big words that you don't hear everyday... it would have been easier if [those words] were bold and the definition – instead of having*

to click on it and going to another page – if it had been right there in the text…like in our biology book…Sometimes, you'll be reading and you see a word you don't know and you don't want to have to click it.

That'd be cool if they gave the pronunciation of the words.

They would throw in a lot of the Latin words for the fishes. To really get the name, you have to really break it down to the Latin roots.

When you went onto the story or the lineage, it says the – I can't even pronounce it, "Sarcopterygii" – it says what the lineage is, but it doesn't really define the word. It says lobed-fins but it doesn't tell what the word itself is.

2. Explain the words in parentheses at the top of the tree (i.e., the names of the orders).

   What are the parentheses below the fish names? I don't know what that is? For example, below hagfish - the word in parentheses?

3. Add more initial information (e.g., to the homepage) to explain the evolutionary tree and how to interpret it (e.g., initially present Fish Stories that focus on how to interpret a tree).

   It would have been nice to have a paragraph explaining the tree more. For example, explaining why in the middle, there was a pitchfork there. I believe it did in one of the fish stories, but it would have been nice to have before…on the homepage. It's different than the other fish stories. It would have been nice to have first.

4. Add a vocabulary list specific to the module, or make the glossary more apparent.

Content Presentation Suggestions

As previously mentioned, participants noted that the manner in which the content was presented did not engage them or draw them into the site. Comments included:

It doesn't hook you…it should be a website that you want to go on to explore new things, but when you do go on it, you are just like, "Oh, I have to do this. It's really boring."

Make it for…not for little kids…but, and this may sound weird; make it less official…less business format.

Color. Bigger font. More pictures. Make it exciting!

In order to make the module more engaging and informative, participant provided the following five suggestions about the presentation of the content on the site:

1. Add more color to the site, especially the homepage.

   Add color to it, so it's just not a plain white background.

   [The green lineages were] the only bright part of the site…it was boring looking.

   If I had to pick between a super colorful page and this one, I'd pick the colorful one. It'd be exciting more…Yes, [add] more color...something more out there that catches your eye.

2. Increase the font size.

   [What I liked least about the site was] how small the font was...how closely flesh the words were.

   In general, it should just be bigger. It's hard to read.

   I wish it was bigger [font] because I had trouble reading it.

3. Add more pictures and add videos to make the module more engaging, visually illustrate concepts, and help break up the text.

   It would be nice to see images of, for example, horizontal semicircular ducts. Or an idea of where it would be located.

   It would be better to have more pictures or videos…Add videos. And, they should make it, so that people, who don't like fish or don't have an interest, would still be like, "That's pretty cool still."

   Videos would be awesome.

   When I'd click on the links, it was kind of boring. I'd kind of doze off or space out when I was reading the information. And, there were only 1 or 2 pictures. I'd be nice to have the information, then the picture, the information, then the picture, so you are not bored.

4. Consider methods to better enable users to read the vertical text on the fish tree, such as adding a scroll-over effect that changes the orientation of words from vertical to horizontal when selected.

How it has the names [of the fish at the top of your tree], if you put your mouse and scrolled over the name, [they should add the feature] that the name would turn and go horizontally [when you scrolled over it] instead of vertically, so you aren't tilting your head over to read it.

It was sideways, so I had to go like this to read it, and it was really little… It's so little and you have to squint even more, you wouldn't read it.

5. Streamline content, to ensure that it is not repetitive.

Most of the information that I was reading was the same description over and over again just the bullets would be different. It was boring…you wouldn't want to read all of it.

The reading aspects – the stories – they weren't boring...they had a little bit of character to them, but I thought they could have been more well-written. Sometimes it seemed a little too repetitive.

Suggestions for Additional Content

In addition to the suggestions already mentioned in prior sections, participants gave the following four suggestions or requests for extra content to be added to the module:

1. Include brief fun facts throughout the site, to help break up the content and engage users.

The content is informative, but it's all bunched up together. You don't just want to read information all the time… It should be the information plus a fun fact…like the lung thing [that some fish have lungs], everybody was interested by that because no one had heard about it. If there were facts [like that], you'd be like, "Oh, that's pretty interesting. I'm going to keep looking at the site." But, if it's just all in the text, some people aren't even going to have read it because they are skimming.

Add fun facts. Something that you'd be like, "Oh, that's cool. I never knew that." Not so much educational facts.

2. Include more information about different types of fish in the module, perhaps by making the images or names of the fish at the top of the tree clickable.

I also would have liked on the tree – how it had the different kinds of fish [at the top] – I would have liked to have been able to click on that to learn more about the different kinds of fish. It seemed like it was mostly focusing on the

tree and the branching. For example, I wanted to look at say, a pufferfish, but I couldn't have clicked on that to see how it related to other fish.

I wanted to click on sharks and rays, but I couldn't.

3. Include additional information about each category of fish, such as the number and the list of specific species within each category.

   I could have been nice for each of the categories – like icefish, anglerfish – to have a number saying how many species are within that category…because there are so many.

   If you could click on each different variation of a fish, and it gives you the list of different fish that fall within that category. If I wanted to know the different species of perches, if I could just go over to it and click on it. It could give me the list of fishes that fall into the perches category.

4. Add games or other interactive elements to the module.

   If you wanted to get kids [on the module], throw a couple of games in there.

Summary and Recommendations

The present study examined the effect of a Web module on engaging and teaching high school students about the evolutionary history of fish and how lineages relate to each other. Although some caution is warranted when interpreting the results, due to the small, heterogeneous group of high school students, the study did generate rich information about users' experiences with the Web module and important insights into how the module influenced their knowledge and attitudes about fish and fish evolutionary science.

Overall, students felt the module content was largely understandable and appreciated the quality of the information provided. In a relatively brief exposure to the Web module, students were able to expand upon previous learning about evolution and natural selection by learning more about how fish evolved and by gaining familiarity with traits common to specific fish lineages. They also learned about traits that evolved in various lineages, such as hermaphroditism and venom. In general, students learned what makes a fish a fish, and they were intrigued to discover previously unfamiliar species of fish. They expressed interest in learning more about these and other types of fish mentioned in the module. Students especially enjoyed the Fish Stories, such as the Googly-Eyed Fishes and Gender-Bending Fish stories. It was clear to them how to navigate through the module, and they cited the dynamic scroll-over effects on the homepage as among their favorite elements to the module.

Recommendations

Re-work the presentation of the content on the site in order to help captivate and engage users, as well as to increase their learning. Users appreciated the quality of the information provided on the module, describing it as solid and informative. However, they noted that the manner in which the content was presented visually (e.g., the lack of color on the site) made it difficult to engage with the module. Participants typically described the site as "boring" and as a resource that they would only use if required. Consider ways to incorporate the participant suggestions below into the module, in order to increase the appeal of the site and better reach the target youth audience. As a result of better engaging youth, more learning can occur when interacting with the module. For example, additional pictures and videos could visually illustrate concepts for users, and making the text more readable (e.g., increasing the size and adjusting the orientation) would help users to better process the information presented.

- Add more color to the site, especially the homepage.
- Increase the font size or add a magnifying scroll-over effect that could be used to enlarge text as needed.
- Add more pictures and add video (e.g., to help break up text).
- Incorporate a scroll-over effect that changes the orientation of the vertical text on the fish tree to horizontal when selected.
- Streamline content to reduce repetition.

Provide additional tools (e.g., pronunciation information) to support vocabulary comprehension throughout the module. While most users understood the module content, those who struggled with it most often noted that the site contained long or complex terms, such as the lineage or species names, that were not defined, broken down, or sufficiently explained. Additionally, the module did not provide users with information regarding pronunciation of these terms. In order for users to feel more comfortable with the Latin or longer words in the module, include pronunciation information, such as hotlinks to audio pronunciations, and definitions for all terms on the same page as the terms themselves, instead of requiring users to open a new browser window to see definitions. Consider adding a module-specific vocabulary list link or making the glossary more apparent.

Add more initial information to the module (e.g., to the homepage) to explain the evolutionary tree and how to interpret it. Given that not all users will be familiar with evolutionary trees, consider ways to help users better understand the particular tree that is the focus of the module. To do so, developers could add dynamic scroll-over effects to the tree itself that provide information about how to read and interpret the tree. Other ideas include: adding a paragraph to the homepage to introduce and explain the tree, better emphasizing the "Review tree-reading basics" link, and initially

guiding users to explore the fish stories that focus on how to read and interpret the evolutionary tree (Percomorphs and Polytomies; Fish on Equal Footing).

Consider ways to draw users to the Fish Stories, especially to increase engagement with the stories about how to read or interpret an evolutionary tree. Users often learned the most from and liked most the Fish Stories, especially those that focused on traits that evolved in various lineages (e.g., the Googly-Eyed Fishes and the Gender-Bending Fish stories). Given that these types of stories were among users' favorite element of the site, consider ways to highlight or make these stories stand out. Additionally, users were least interested in the stories that focused on how to read or interpret an evolutionary tree. Explore methods to draw users to these types of stories, especially since the information contained in the stories is important for users to be able to better understand the tree itself.

Include even more information within the module about different types of fish, for example, by making the images of the fish at the top of the tree clickable. Participants enjoyed learning about previously unfamiliar species of fish in the module and wanted information about even more types of fishes (e.g., to be able to click on the pufferfish and learn more).

Increase the number of interactive elements within the module, such as adding games or clickable Q&A fun facts. While usability feedback was not a focus of the current study, students did provide ideas for improvements to the module. The youth particularly enjoyed the interactive portions of the module (i.e., the scroll-over effects on the homepage) and requested that the module be made even more engaging. Since interactive site elements can foster learning and engagement, it may help to integrate more interactivity into the module (e.g., by adding games or an interactive quiz). Adding a greater number of such elements will also likely increase accessibility for younger populations. To help divide up the content and make the learning more fun, participants also suggested that fun facts be added to the site, which could be done by adding interactive questions or facts to the module, perhaps on the sidebar of pages. When users click on or scroll over the question text, the answer could appear.

Further explore student learning from the module, particularly with an aim to better understand task performance and the degree of student learning specifically regarding the evolutionary tree. Students were typically unsure of their answers for the module tasks, answering tasks correctly on average only 56% of the time. Participants performed best on Tasks 2, 3, and 7, and worst on Tasks 6 and 8 (with 20% or less of participants responding correctly). Further exploration and data are needed to fully understand why some tasks were easier for participants than others. It is important to be able to understand any barriers to correctly completing the tasks, and in turn, to learning.

From interacting with the module, participants frequently learned about specific traits (e.g., hermaphroditism) that evolved in lineages or previously unfamiliar species of fish. It was not clear though if participants connected this learning back to the evolutionary tree. For example, participants learned that some fish had the trait of tubular eyes, but it was not clear if they learned that this trait evolved in various lineages and in which lineages it evolved. Furthermore, in the group discussion, participants hardly ever mentioned learning about lineages or the names or traits common to a specific lineage. Clearly, further research is needed to more fully understand student learning from the module.

Fix the freezing problems with the scroll-over effects on the homepage. The dynamic scroll-over effects on the homepage for the lineages and Fish Stories were among users' favorite elements of the site, however users complained that these effects would often freeze, requiring them to reload the homepage in order for the effects to work again. Explore the root cause of this freezing, and ensure that the scroll-over effects work on a variety of platforms and browsers.

Appendix A: Task-Specific Performance and Feedback

In the eight sections that follow, we present participant answers and feedback for each of the Web module tasks.

Task 1 – What is the name of the specific branch that led to tetrapods?

Only four out of the ten participants correctly answered Task 1, noting that the "Sarcoptergii" lineage led to tetrapods (Table 5). One participant explained her answer:

> *I looked in one of the stories [From Water to Land] to find it. I don't remember how, but I did.*

Of the six who answered the question incorrectly, two participants mistakenly listed the name of the Fish Story (From Water to Land) that appeared below tetrapods, on the same branch as the sarcoptergii lineage. Three provided the wrong lineage(s) (e.g., vertebrata), and one listed the name ("lobe-finned fishes") that appeared at the top of the branch alongside tetrapods (i.e., "lobe-finned fishes & tetrapods"), commenting:

> *I just wrote down what it said next to it: lobe finned fishes.*

> *I had no idea.*

Table 5: Task 1 – Correct & Incorrect Answers

Task 1 – What is the name of the specific branch (or lineage) that led to tetrapods (four-limbed vertebrates that includes humans)? (n=10)				
Correct				**Incorrect**
%	**n**	**Answer**	**n**	**Answers**
40%	4	*Sarcopterygii*	6	*Vertebrata (n=2)* *From Water to Land (n=2)* *Lobe-finned fishes* *Craniata, osteichthyes, gnathostomata, vertebrata*

Task 2 – Identify two features shared by all fish.

Participants performed the best on Task 2, with all but one of the participants (n=9) answering it correctly (Table 6). Two portions of the module provided correct answers to this item: (a) the Craniata lineage on the homepage and (b) the What is a Fish? story. The majority of respondents drew their answers from the Craniata lineage (n=7), while two used the What is a Fish? story. Participants provided a variety of correct features shared by all fish, with "braincase surrounding the brain" being the most frequently listed (n=7).

Table 6: Task 2 – Correct & Incorrect Answers

Task 2 – Identify two features shared by all fish. (n=10)				
Correct				**Incorrect**
%	**n**	**Answer**	**n**	**Answers**
90%	9	*Braincase surrounding brain, complex endocrine system* (n=3) *Have brain protected by a braincase and an obvious head region with eyes, teeth, and other sensory organs* (n=2) *Gills and heart* (n=2) *Braincase surrounding brain & gills* *Braincase surrounding brain & hemoglobin present in blood*	1	*Fins and gills*

Task 3 – Identify the specific branch that has a unique type of scale called placoid and venom.

Participants also did well on Task 3 – see Table 7. Only one participant (out of six) answered this task incorrectly, providing a lineage that had solely evolved venom (not placoid sales) as the answer: "Scorpaeniformes" (scorpion fish). Some of the participants who answered the question correctly explained how they generated their answers:

> *That one was a little tricky…I had trouble with it at first, until I went to the different stories that explained the different fish that have venom [Oh Fish, Where is Thy Sting?], and it said "shark and rays", so I went to the lineage, and it showed up on that one.*
>
> *I saw the word "placoid", so I just put that one [chondrichthyes].*

Table 7: Task 3 – Correct & Incorrect Answers

Task 3 – Identify the specific branch (or lineage) that has a unique type of scale called placoid and venom. (n=6)				
Correct				**Incorrect**
%	**n**	**Answer**	**n**	**Answers**
83%	5	*Chondrichthyes*	1	*Scorpaeniformes*

Task 4 – How many lineages independently evolved hermaphroditism?

Two thirds of the participants (n=4) who answered Task 4 gave the correct answer (Table 8). One participant correctly explained that she discovered the number of lineages that independently evolved hermaphroditism (i.e., eight) by looking at the Gender-bending Fish story:

> *Within the story, there were the highlighted branches.*

The two participants who answered incorrectly (i.e., three or one lineage) did not provide an explanation for how they had generated their responses.

Table 8: Task 4 – Correct & Incorrect Answers

Task 4 – How many lineages (or branches) independently evolved hermaphroditism? (n=6)				
Correct				**Incorrect**
%	**n**	**Answer**	**n**	**Answers**
67%	4	*Eight*	2	*Three* *One*

Task 5 – Describe two characters or traits that are shared by all gnathostomes.

Four of the six respondents answered Task 5 correctly, providing various characters from the gnathostomata lineage scroll-over information on the tree (Table 9). Two participants could not find the answer to this item, with one specifying that she was confused by the difference in the term used in the question ("gnathostomes") versus in the tree lineage ("gnathostomata"):

> *It was the ending that tripped me up. It was plural [on the tree] – "gnathostomata." Things can be so different in science – one or two letters are different, and it could be a completely different definition. So, I didn't know…I didn't know if I was just missing something…I didn't get that one.*

Table 9: Task 5 – Correct & Incorrect Answers

Task 5 – Describe two characters or traits that are shared by all gnathostomes. (n=6)				
Correct				**Incorrect**
%	**n**	**Answer**	**n**	**Answers**
67%	4	*Upper and lower jaws; paired nostrils* (n=2) *Series of gill arches & paired fins* *Series of gill arches & horizontal semicircular ducts*	2	*Maybe I'm just being blind today, but I can't find anything involving that word.* *I couldn't find it?*

Task 6 – Identify the specific branch or lineage that has evolved tubular eyes, bioluminescence, AND hermaphroditism.

Out of all eight tasks, participants performed the worst on Task 6, with only one out of eight participants correctly completing this task (Table 10). Task 6 proved challenging because it required participants to visit and compare highlighted branches on trees in three different sections of the module (the Googly-Eyed Fishes, A Light in the Darkness, and Gender-Bending Fish stories), in order to find the sole highlighted branch common to all three trees (i.e., lizardfish). Figure 3 displays an example of one of these three trees (i.e., the tree in the Googly-Eyed Fishes story).

Several participants did not understand the question at all – see comments in Table 10, as well as:

> *This task was really confusing.*

However, several other participants who answered incorrectly, had the right idea about how to find the answer – that is, looking for the common highlighted branches across the stories. However, participants could not easily look at and compare all three trees from the stories at the same time, since the trees appeared on different pages of the module. Perhaps due to this difficulty, two participants, in addition to listing the lizardfish (which was highlighted on all three stories), inaccurately also wrote down the anglerfish (which was highlighted on two out of the three stories) in their answers. One participant incorrectly explained:

> *I think it was two fishes: anglerfish and lizardfish, since when I clicked and looked at those three [stories], those were the only two that had all three of those characteristics.*

One participant wrote down all four of the lineages highlighted in the Googly-Eyed fish story. Two participants wrote down one of the green lineages from the homepage tree (i.e., actinopterygii), with one explaining that she was confused about what constituted a lineage:

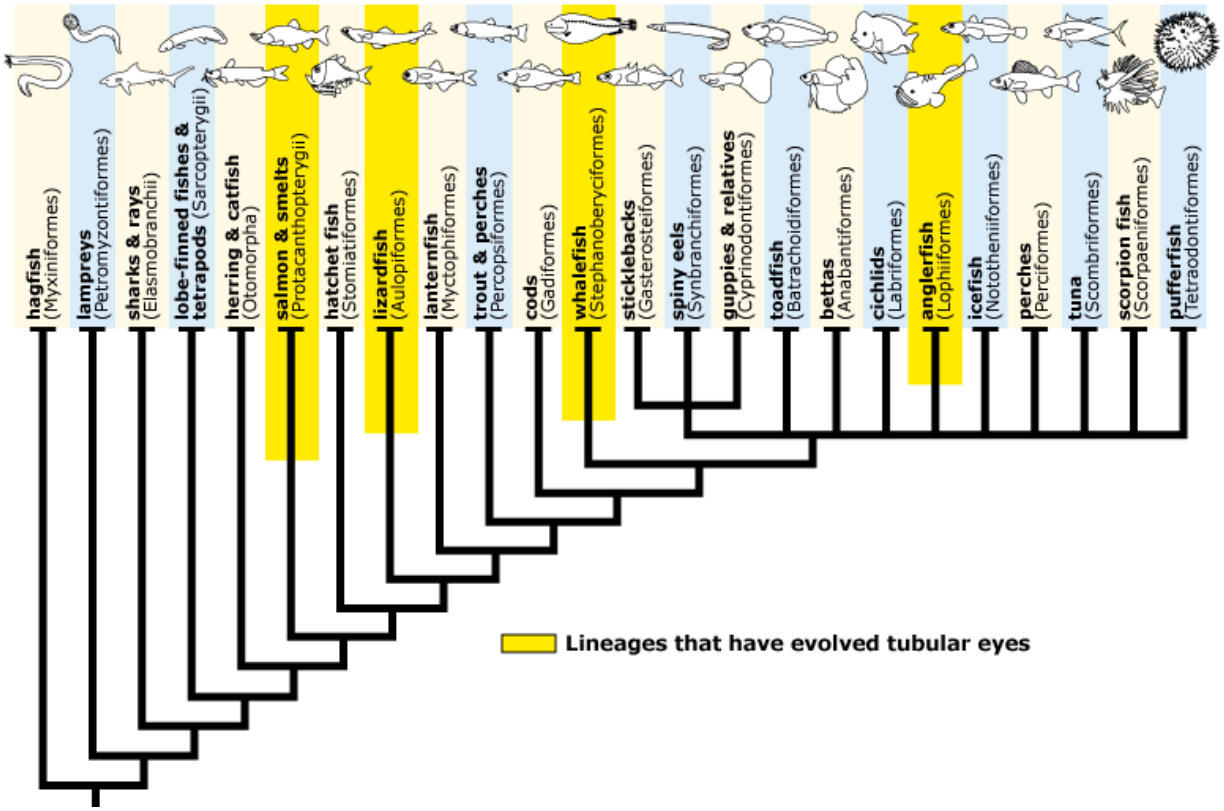
> *I was looking forever. I went to the Google Eyes [story], and then it highlighted the anglerfish. I tried to do process of elimination. It highlighted those, so I went to anglerfish that I knew had bioluminescence and that highlighted more, which led me to the perch…It also confused me because [the task] said the lineage, too, so I wasn't sure if I was looking at the green highlighted things for the answer, which confused me.*

Table 10: Task 6 – Correct & Incorrect Answers

Task 6 – Identify the specific branch or lineage that has evolved tubular eyes, bioluminescence, AND hermaphroditism. (n=8)				
Correct				**Incorrect**
%	**n**	**Answer**	**n**	**Answers**
14%	1	*Lizardfish*	7	*Lizardfish and anglerfish* (n=2) *Actinopterygii* (n=2) *Salmon and smelts, lizardfish, whalefish, anglerfish* *I am not quite sure* *This question is confusing. I tried, but I didn't understand how/where to find that info.*

Figure 3: Googly-Eyed Fish Story

(Tree highlighting lineages that have evolved tubular eyes)



Task 7 – Name two specific branches that are part of a polytomy on this tree.

The majority of participants (five out of seven) answered Task 7 correctly (Table 11), listing a variety of branches that were part of the two polytomies on the tree. Of the two who answered incorrectly, one student could not find the answer so did not provide a response, while the other wrote down the name of one of the Fish Stories on this topic (Percomorphs and Polytomies).

Table 11: Task 7 – Correct & Incorrect Answers

Task 7 – Name two specific branches (or lineages) that are part of a polytomy on this tree? (n=7)				
Correct				**Incorrect**
%	**n**	**Answer**	**n**	**Answers**
71%	5	*Sticklebacks, spiny eels, guppies* *Sticklebacks, guppies & relatives* *Toadfish & betta* *Batrachoidiformes, Anabantiformes* *Pufferfish & tuna*	2	*Percomorphs and polytomies* No answer

Task 8 – Identify one character/trait that would allow you to distinguish a herring from a pufferfish.

The participants performed poorly on Task 8, with only one of six respondents answering the item correctly by providing characters listed in the Actinopterygii lineage scroll-over information on the tree (Table 12). Those who answered incorrectly seemingly generated answers based on the images of the two fishes at the top of the tree. Two respondents explained that they found the task difficult either because they could not click on images of the herring and pufferfish to find out more information or because they did not know that a herring was a fish:

> *I didn't know what they meant. I couldn't click on the pufferfish or the herring and read the characteristics. So, I didn't get that one. I didn't know what to do.*

> *Oh, I didn't get that one. I didn't know what a herring was. I didn't know it was a fish. I thought it was something about the pufferfish.*

Table 12: Task 8 – Correct & Incorrect Answers

Task 8 – Identify one character/trait that would allow you to distinguish a herring from a pufferfish? (n=6)				
Correct				**Incorrect**
%	**n**	**Answer**	**n**	**Answers**
20%	1	*Endoskeleton & fin muscles that do not extend far into the paired fins.*	5	*Pufferfish have spikes that pop out.* *The spikey features and roundness found in a pufferfish but not in a herring.* *Pufferfish inflate like a balloon when they feel threatened by predators.* *I couldn't really find the answer. The pufferfish doesn't have specialized traits.* No answer