Survival of the stickleback

Changes in a species over time (7.5)

SEEd Performance Expectation(s):
Standard 7.5.1: Construct an explanation that describes how the genetic variation of traits in a population can affect some individuals’ probability of surviving and reproducing in a specific environment. Over time, specific traits may increase or decrease in populations. Emphasize the use of proportional reasoning to support explanations of trends in changes to populations over time. Examples could include camouflage, variation of body shape, speed and agility, or drought tolerance.

Phenomenon: Stickleback in Loberg Lake change from having spines to having no spines in a very short time span.

Lesson Performance Expectations (written in 3D framework):
- Ask questions about what is causing the changes in the populations of stickleback in Loberg Lake.
- Ask questions about the function of the pelvic spine and how that relates to the survival of the stickleback.
- Analyze data for patterns and to find supporting evidence for claims about structure and function of the stickleback spine.
- Analyze data to construct an explanation based on evidence that explains the phenomenon (changes to the population of stickleback in Loberg Lake).
- Analyze data to engage in an argument from evidence to determine the best answer to the phenomenon.
- Analyze data to determine which data is relevant to understand the stickleback phenomenon.
- Construct an explanation based on evidence that explains the changes to the stickleback populations in freshwater environments.

Student Learning Performances

Gathering (obtain information, ask questions, plan and carry out investigations, use models to gather data and info, use mathematic/computational thinking)

Asking Questions about the Phenomenon (Changes to Stickleback Populations)
1. Students are presented with the phenomenon. As students watch the video, they record any questions they have about the phenomenon. Students are then presented with the first round of data that includes the maps of stickleback populations and the population’s changes to Loberg lakes. Students are asked to determine the patterns they observe. Patterns can be regional, global, or both. While students are observing the data hand out sticky notes for students to write their questions on, provide a space to put questions. Give students about 15 minutes to observe the data, determine patterns, and ask questions. The teacher can ask students to share the patterns they observed. However, the teacher should not explain why these patterns occurred.

2. Students categorize questions into topics. The teacher facilitates a discussion highlighting the value of different questions and their topics. The questions should be used to guide students to deepen their definition of the phenomenon and how we could find the answer. Discussion points could include whether the questions are productive, leading to next steps, or inquisitive, interesting but may not be answered during this exploration. The teacher should encourage all types of questioning and have students themselves classify the questions on the board.

3. Before the students move on to the different explanations the teacher should ask the students to have a quiet write about what they think the overarching question posed by the phenomenon is. This write can be in a science journal, notebook, or a piece of paper to be turned in later.

Reasoning (evaluate information, analyze data, use mathematics/computational thinking, construct explanations, develop arguments from evidence, use models to predict and develop evidence)

Analyzing Data to Support Claims About Changes to Stickleback
4. The teacher tells students that they will be looking at different explanations that may answer the question(s) posed by the phenomenon.
5. In the small groups, students analyze explanation A. Their objective is to read the explanation and make sense of the data that accompanies the explanation. How does understanding the size and growth chart help us to understand the structure and function of As students analyze the data they are presented with and make sense of the explanations, they can discuss the following questions as a group (each group member needs to be prepared to answer):

- How does the graphs and explanation of size and growth rate help us to understand the cause and/or effect of our phenomenon?
- How do these graphs and explanation help us to understand the structure/function of the spines (or absence of) of the stickleback?
- How do these graphs and explanation help us in our overall understand of the phenomenon?
- Can you find patterns in any of these graphs that help answer your urgent questions?
- Do you have any new questions to add? (If so, write them on your sticky note and add them to our questions chart.)

As students are making sense of the explanation and graphs, the teacher checks in with each group. The teacher should not tell students the answers to the questions (or the upcoming explanations), but might need to help students. Questions that the teacher might ask to individual groups:

- What does each graph mean?
- Why would the differences between the growth rates be important?
- Why would the differences in overall size between marine and freshwater populations be relevant?
- What pattern do you observe in this graph?

6. As the students work through their understanding of the explanations and the data presented, the students continue to add their questions to the question board. Adding new categories as necessary to the board. Students can start to self-sort the questions.

7. The teacher asks students if they know of factors that might be causing our phenomenon (predation, other environmental factors). Students brainstorm answers with a partner and share ideas with the class. The teacher should ask students whether explanation A answered questions and/or created more questions. The questions raised by the new data should be discussed and ways to answer them should be explored as a group.

**Analyzing data to understand the role that predators have on the Stickleback populations**

8. To continue to explore the phenomenon the teacher shows a short clip that explores the idea of predators and the effects that they have on the stickleback populations. The teacher next hands out explanation B and the corresponding data, and asks the students to analyze the new data.

- How does the graphs and explanation of the different predators help us to understand the cause and/or effect of our phenomenon?
- How do these graphs and explanation help us to understand the structure/function of the spines (or absence of) of the stickleback?
- How do these graphs and explanation help us in our overall understand of the phenomenon?
- Can you find patterns in any of these graphs that help answer your urgent questions?
- What patterns do you notice in the writing of explanation A and B?
- Do you have any new questions to add? (If so, write them on your sticky note and add them to our questions chart.)

9. As a whole class, the teacher selects 1-2 student groups to explain their analysis of analysis of explanation B. The teacher should lead a discussion that can articulate specific patterns that they noticed on the graphs and data. Of note on each graph for discussion:

**Number of predatory fish species**
- The overall length of the spines increases when the number of predatory fish also increases.

**Handling Time and Escapes from predators**
- Handling time is the amount of time a predatory fish is trying to eat the stickleback.
- The handling time increases in sticklebacks with longer spines.
- The longer the handling time the higher the likelihood that the stickleback will escapes from a predatory fish.

**Dissolved Calcium and stickleback populations**
- The highest levels of dissolved calcium has only the spined sticklebacks.
- In lower levels of dissolved calcium, there are both the spined and non-spined sticklebacks present.
- The presence of predatory fish does not dramatically change the populations of sticklebacks (spined versus no-spine).

**Dragonfly Larva predation**

- The dragonfly larva preyed on both spined and no-spined stickleback indiscriminately.
- The dragonfly larva predominantly preyed on the smaller stickleback.

10. To continue to explore the phenomenon the teacher shows more of the full video that explains the gene switches that control the gene Pitx1, the gene shown to be responsible for the spine structure. After the video, the teacher next hands out explanation C and the corresponding data, and asks the students to analyze the new data.

- How does the graphs and explanation of the different predators help us to understand the cause and/or effect of our phenomenon?
- How do these graphs and explanation help us to understand the structure/function of the spines (or absence of) of the stickleback?
- Can you find patterns in any of these graphs that help answer your urgent questions?
- What patterns do you notice in the writing of explanation A and B?
- Do you have any new questions to add? (If so, write them on your sticky note and add them to our questions chart.)

11. As a whole class, the teacher selects 1-2 student groups to explain their analysis of analysis of explanation C. The teacher should lead a discussion that can articulate specific patterns that they noticed on the graphs and data. Of note on each graph for discussion:

**Gene switches**
- The gene Pitx1 is not mutated and functions normally in both the spined and no-spined stickleback.
- The mutations occur in the promoter region of the Pitx1 that controls expression in the pelvis.

**Expression of Pitx1**
- Pitx1 is expressed in the mouth in both the spined and no-spined sticklebacks.
- Pitx1 is only expressed in the pelvis of the spined sticklebacks.

**Changes to Pitx1 expression in other organisms**
- Changes to the expression of Pitx1 occur in other organism.
- The loss of expression of pitx1 can explain why manatees no longer have legs, but are genetically closely related to elephants.

*Communicating (communicate information, argue from evidence (written and oral), use models to communicate)*

12. After discussion on explanation C, the teacher should direct the discussion towards the structure of explanation C. How is the structure of explanation C similar/different from that of the other two explanations?

13. The teacher should direct students to write a complete explanation for the answer to the overarching question: “What is the cause and function of the changes to the stickleback population in Loberg Lake?” Students will write their explanation in the area provided below.

14. After all students have completed their writing, they are assigned a partner. The students follow the CCCR rules to share their writing. After each student reads his or her writing, the partner who is listening offers constructive feedback on the explanation. After both partners have shared their writing and received feedback, they revise using a different color pen or pencil.

15. During or immediately after the CCCR, the teacher hands out the explanation tools and sentence strips. Students sort the strips into evidence and science concepts. As they sort the data, they should discuss whether they used these pieces of evidence in their own writing, and whether these help to support their claim. After the students have sorted all teacher provided strips the students should be directed to identify areas of presented data that are lacking a corresponding strip. Any topics/graphs without a strip should have one written by the students.

16. The teacher should lead the discussion on the difference between the evidence and the science concepts. When we write how can we identify either? The teacher should direct the students to use different colored pencils in explanations A, B, and C to identify the
evidence and science concepts in the explanations. Where are each located in the writing? Students can do the same with their own writing to determine whether their writing has the correct format.

The teacher can then lead the discussion on which evidence did not have an evidence strip and have students share their examples of an appropriate summary of the evidence. The teacher should use this as an opportunity to identify continued misconceptions of the data and have the class discuss.

17. Students should be arranged in NEW groups of 3-4 students each. Within the group, the students are each given an argument tool worksheet and asked to form a consensus on the claim, evidence and reasoning that answers our overarching question. Each student is asked to write his or her own explanation. Prior to writing students should:

- Examine data again and continue to discuss which data is relevant.
- Come up with a consensus claim.
- Decide as a group which data to use to support that claim.
- As a group determine what the reasoning is that ties the claim to the evidence.
- After the group has determined the best claim, evidence and reasoning that explains our phenomenon each member of the group writes their individual explanations.

18. After each group has written their CER, the groups should be paired. Similar to the CCCR the groups each share their claim and the evidence they used to support their claim. The groups then discuss the differences in the claims and evidence used. They should discuss the following points:

- Do all of the other groups’ ideas make sense?
- Does their data support their claim?
- Is there data that is left out the pokes a hole in their claim?
- Does hearing their explanation help overall understanding of the phenomenon?

19. After the multi-group discussion, groups should go back and write a rebuttal based on the discussion. This should include the points brought up by the other group.

<table>
<thead>
<tr>
<th>Science Practices</th>
<th>Analyze and interpret data</th>
<th>Construct an explanation</th>
<th>Obtaining, evaluating, and communicating information</th>
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<td>Engaging in argument from evidence</td>
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<td>Crosscutting Concept(s)</td>
<td>Patterns</td>
<td>Structure and function</td>
<td>Cause and effect</td>
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<td>Disciplinary Core Ideas</td>
<td>MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals’ probability of surviving and reproducing in a specific environment.</td>
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(Template adapted from B. Moulding, 2011)

Materials

- Video on sticklebacks (video found [here](#) and [here](#))
- Stickleback engage data: Loberg Lake data, maps of areas
- Explanations: A, B, C
- Explanation Datasets
- CCCR student and teacher explanations
- Argumentation Tool
- Evidence Tool
- Sentence Strips
<table>
<thead>
<tr>
<th>episode</th>
<th>Phenomena and Data and Time provided by teacher</th>
<th>Student Response</th>
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</table>
| 1       | **Management Strategy:**                       | Students organize into learning groups  
|         | Video: Making of the fittest, evolution of the stickleback (stop at 2:36) [Link](https://www.youtube.com/watch?v=Pv4Ca-f4W9Q) | Students look for patterns and ask questions |
|         | **First Data Set:** logberg lake data and images of sticklebacks |  |
|         | Figure from Bell et. al. showing locations of sampling sites, sampling sites (A–E) and isobaths (m) within Loberg Lake. |  |
|         | [Image](image.jpg)  
|         | Figure from Bell et. al. “Twelve years of contemporary armor evolution in a threespine stickleback population.” *Evolution*, 58(4), 2004, pp: 814-824 |  |
Figure 1: from the following website
http://life.bio.sunysb.edu/ee/belllab/loberg.html

Relative % of stickleback population with a pelvic spine (o) versus no-spine (o) in Loberg Lake, Alaska

2 Teacher Leads discussion
Sort questions by topic
Define data needs and questions to help construct explanation of the phenomenon

3 Provide writing prompt for quiet write
Students complete first write

4 Transition to next data set with student questions
Students complete first write and prepare for more data

5 Provide Students with Explanation A
Second Data Set: Distribution of the Stickleback in the Kenai Peninsula
Analyze and interpret data
Discuss data with group
Distribution of sticklebacks in the Kenai Peninsula (Southern Alaska). Lakes were sampled for stickleback population and the presence or absence of a pelvic spine was recorded. The circles represent the proportional amounts of sticklebacks found. Black = spine, white = no spine. Lakes are stippled, streams and rivers (solid and broken lines). Figure from Bell and Orti “Pelvic Reduction in Threespine Stickleback from Cook Inlet Lakes: Geographical Distribution and Intrapopulation Variation.” Copeia 1994(2), pg 314-325.

Circulate the room and ask guiding questions
What does the graph mean?

6  Facilitate question asking and data analysis

Ask more questions, sort by topic

7  Ask: What could be causing this phenomenon?
Does explanation A provide all the information necessary to answer the overarching question?

Students determine what information they need.

8  Movie clip: making of the fittest evolution of the stickleback (start again show to 3:30)
Provide Students with Explanation B

Read Explanation B
Read/Analyze new data on predators and salinity/calcification
Figure 1: Length of the pelvic spine and the number of predatory fish present in the environment of a 3-spined stickleback. As the number of predatory fish increases, there is a positive association with the length of the pelvic spine.

Figure 2: Frequency of escapes compared to the length of time a fish is handled by a predator. As the amount of time a fish is handled increases, the more likely they are to escape the predator. This likelihood of escape increases when the length of spines are longer. Figure from T.E. Marchinko “Predator handling failures of lateral plate morphs in gasterosteus aculeatus: functional implications for the ancestral plate condition” Behavior 137: 1081-1096

Figure 3: The relationship between dissolved calcium and the abundance of predatory trout in 33 lake populations. Circles represent stickleback with short or no pelvic spines. Triangles represent stickleback with full spine. Figure from T.E. Marchinko “Predator handling failures of lateral plate
morphs in gasterosteus aculeatus: functional implications for the ancestral plate condition” Behavior 137: 1081-1096

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<td>% of total</td>
<td>97.8</td>
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Figure 4: Predation of stickleback fish by Aeshna (dragonfly larva). Different sizes of sticklebacks were presented to dragonfly larva and the number of fish eaten were measured. Tank A, B, C represented three trials of the experiment and the experiment lasted for 25 days with fish replaced every 6 days. The author found no difference between the number of fish eaten with and without spines. Figure from T.E. Marchinko “Spine deficiency and polymorphism in a population of Gasterosteus aculeatus: an adaptation to predators?” Can. J. Zool. Vol 58 1980

Figure 5: Stalking and capturing of a prey by a dragonfly larva. Figure from T.E. Marchinko “Spine deficiency and polymorphism in a population of Gasterosteus aculeatus: an adaptation to predators?” Can. J. Zool. Vol 58 1980

Average length of female sticklebacks sampled at different locations. Samples were taken in Sweden and Finland in marine and inland populations.

Data was taken from DeFaver and Merila “Variation in Age and Size in Fennoscandian Three-Spined Sticklebacks (Gasterosteus aculeatus)” PLoS One 8(11): e80066.
<table>
<thead>
<tr>
<th>9</th>
<th>Discuss data analysis: results on storyline</th>
<th>Students share their explanations. Review language for engaging in scientific argument</th>
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<tr>
<td>10</td>
<td>Phenomenon video: Making of the fittest (start to end)</td>
<td>Students watch video Read/respond Explanation C Analyze Pitx1 data</td>
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<td>Explanation C Data for explanation C</td>
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<td><img src="image" alt="Growth Rate of Sticklebacks" /> Overall growth rate of stickleback in salt water compared to freshwater conditions. Data was taken from Barrett, Rogers, and Schulte “Environment-specific gene expression facilitates divergence at the ectodysplasin locus in threespine stickleback”. Evolution 63:11:2833-2837.</td>
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<td>Select groups share analysis</td>
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<td>12</td>
<td>How is structure of Explanation C different than</td>
<td>Prepare to write answer to</td>
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<td><strong>Explanation A or Explanation B?</strong></td>
<td>overarching question as claim</td>
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<td><strong>13</strong></td>
<td>Present overarching question for reflection</td>
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<td><strong>14</strong></td>
<td>CCCR strategy (see description below)</td>
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<tr>
<td><strong>15</strong></td>
<td>Pass Out Explanation Tool and sentence strips</td>
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<td><strong>16</strong></td>
<td>Colored pencils</td>
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</table>
| **17** | Regroup students  
Provide Argument Tool - complete claim |
| **18** | CCCR with another group |
| **19** | Complete counterclaim |

*Journal Reflection: What is the cause and function of the change in the stickleback population in Loberg Lake?*

*find a partner. Students read their claim in response to the question to each other*

*Students match evidence to concepts*

*Use colored pencils to identify concepts vs evidence*

*Students join new group Students come to a consensus on a group claim*

*Share and review evidence*

*Write counterclaim and rebuttal*
Figure from Bell et. al. showing locations of sampling sites, sampling sites (A–E) and isobaths (m) within Loberg Lake.

Figure from Bell et. al. “Twelve years of contemporary armor evolution in a threespine stickleback population.” *Evolution*, 58(4), 2004, pp: 814-824
First Write -

What do you think is causing the change in the stickleback population in Loberg Lake?
Example Explanation A:
Overarching Question: What is the cause and function of the changes seen in the stickleback populations?
Question: Why did freshwater sticklebacks evolve to have no-spines?
Sticklebacks without spines have a faster growth rate, but a smaller overall size, than the sticklebacks with spines. As evidenced by the graph from Loberg Lake, populations of sticklebacks in freshwater environments evolve from high percentages of sticklebacks with spines to high percentages of sticklebacks without spines. The growth rates of sticklebacks in freshwater with no spines is 0.124 mm/day and in saltwater environment is 0.122 mm/day. The growth rate of sticklebacks with spines is 0.116 mm/day in freshwater and 0.123 in salt water. The average size of adult freshwater sticklebacks sampled in different environments are: 45
mm, 42 mm, 53 mm, 45 mm, and 40 mm. This is smaller in size than the populations of sticklebacks found in saltwater. The average size of saltwater sticklebacks are: 50 mm, 60 mm, and 56 mm. The absence of the spines allow the freshwater stickleback to grow faster but their relative size is smaller, this might allow the stickleback without spines to survive better in a freshwater environment than the stickleback with the pelvic spine.
Distribution of sticklebacks in the Kenai Peninsula (Southern Alaska). Lakes were sampled for stickleback population and the presence or absence of a pelvic spine was recorded. The circles represent the proportional amounts of sticklebacks found. Black = spine, white = no spine. Lakes are stippled, streams and rivers (solid and broken lines). Figure from Bell and Orti “Pelvic Reduction in Threespine Stickleback from Cook Inlet Lakes: Geographical Distribution and Intrapopulation Variation.” Copeia 1994(2), pg 314-325.

Example Explanation B:
Overarching Question: What is the cause and function of the changes seen in the stickleback populations?

Question: Why are not all sticklebacks small with no pelvic spine?

Sticklebacks without spines can evade predation from dragonfly larva easier but are more susceptible to being eaten by larger predatory fish. The length of the pelvic spine has been shown to increase with an increase in the number of predatory fish species that live in the same environment of the stickleback. In fish with complete spines a handling time of 30-60 seconds increases the number of escapes from 10% of the time to more 20% of the time, and more than 40% of the time when the handling time is above 60 seconds. Fish with low spines (no or short pelvic spines) handling times of 30-60 second only results in escapes 5% of the time. When handling time increases over 60 seconds the escape rate increases to 25% of the time.

Dragonfly larva favor smaller sized fish and prey predominantly on fish from 15-25 mm in size. When predatory fish are present, fish with full spines are more likely to evade capture, but when there are no predatory fish present then a rapid growth rate helps to avoid predation by the dragonfly larva.

The fresh water environment provides different levels of nutrients which would favor the fast growing, no-spined sticklebacks. When dissolved calcium is above 10 mg/L in lakes only stickleback with a full pelvic spine are found. When dissolved calcium was between 2 and 4 mg/L both spined and no-spined sticklebacks are found. When dissolved calcium is at 2mg/L or below only no spined fish were present. The presence of the predatory fish did not appear to affect which populations of sticklebacks fish were found. The levels of dissolved calcium had a greater effect on the populations of sticklebacks found in lakes than the numbers of predators present.

Stop and reflect: How do explanations A and B compare to your ideas about what is causing the changes to the stickleback population in Loberg lake?
Figure 2: Frequency of escapes compared to the length of time a fish is handled by a predator. As the amount of time a fish is handled increases, the more likely they are to escape the predator. This likelihood of escape increases when the length of spines are longer. Figure from T.E. Marchinko "Predator handling failures of lateral plate morphs in gasterosteus aculeatus: functional implications for the ancestral plate condition" Behavior 137: 1081-1096.
Figure 3: The relationship between dissolved calcium and the abundance of predatory trout in 33 lake populations. Circles represent stickleback with short or no pelvic spines. Triangles represent stickleback with full spine.
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Figure 5: Stalking and capturing of a prey by a dragonfly larva.
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Average length of female sticklebacks sampled in 8 different locations. Samples were taken in Sweden and Finland in marine and inland populations.

Data was taken from DeFaveri and Merila “Variation in Age and Size in Fennoscandian Three-Spined Sticklebacks (Gasterosteus aculeatus)” PLOS One 8(11): e80866.

Overall growth rate of stickleback in salt water compared to freshwater conditions.

Data was taken from Barrett, Rogers, and Schulter “Environment specific pleiotropy facilitates divergence at the ectodysplasin locus in threespine stickleback”. Evolution 63-11:2831-2837.
Overarching Question: What is the cause and function of the changes seen in the stickleback populations?

Question: What causes the presence or absence of the stickleback pelvic spine?

Sticklebacks that do not have spines have a change in their DNA that does not turn on the Pitx1 gene, and sticklebacks that do have spines do not have this change and Pitx1 is turned on in the pelvis. The expression of Pitx1 in the marine sticklebacks shows the gene turned on in the mouth, jaw and pelvis. Expression of Pitx1 in freshwater sticklebacks shows only expression in the mouth and jaw but not pelvis. The sequence of the switches to the Pitx1 gene in the freshwater sticklebacks showed differences in the DNA from those of the marine sticklebacks. Looking at several populations of fish, the change in the DNA switch for the Pitx1 gene was found in all fish that lost the pelvic spine. In manatees a change in the Pitx1 switch was also observed.
Data Explanation C

Figure 1: Expression of the Pitx1 gene. Fish in A, C, and D are marine samples with expression of Pitx1 in the mouth and pelvis. Green circles highlight expression in the pelvis. Fish in B, E, and F are freshwater samples with expression in the head but not the pelvis. Red circles highlight absence of expression in the pelvis. Figure from M.D. Shapiro, et. al. Genetic and developmental basis of evolutionary pelvic reduction in threespine sticklebacks. Nature 428: 717-723. Correction.

Figure 2: In the marine stickleback the switches to turn on the Pitx1 gene are functional and the gene is turned on in the mouth, jaw and pelvis. In the freshwater stickleback there are mutations present in the switch to turn on the gene in the pelvis and the Pitx1 gene is only turned on in the mouth and jaw. Figure from https://ncse.com/book/export/html/2585.

Figure 3: Loss of the switch that turns on Pitx1 in the pelvis occurs in many different organisms. The loss of the switch was found in freshwater stickleback species. The manatee also has the same loss of the Pitx1 switch in the pelvis and may be the reason that the manatee lost its hind limbs. Figure from M.D. Shapiro, M.A. Bell, and D.M. Kingsley. Parallel genetic origins of pelvic reduction in vertebrates. Proceedings of the National Academy of Sciences of the USA 103: 13753-13718.
<table>
<thead>
<tr>
<th>Step in the strategy</th>
<th>What to do during the step</th>
</tr>
</thead>
</table>
| Consider             | ■ This is an individual step. Work quietly.  
                        ■ Consider, or think about, a question or problem.  
                        ■ Record your best ideas in your science notebook.  
                        ■ If you are using words to record your answer, write in complete sentences.  
                        ■ If you are using sketches or drawings to record your answer, make a clear sketch that includes labels. |
| Contribute           | ■ This is a partner step.  
                        ■ Contribute your ideas to a discussion with your partner by doing the following:  
                        ■ If you used words to record your ideas, read the sentences aloud, word for word. Do not add any additional explanation.  
                        ■ If you used sketches to record your ideas, explain the sketches carefully, including the labels.  
                        ■ Answer any questions your partner might have.  
                        ■ Watch your partner for signs of confusion.  
                        ■ Take turns so that each partner has an opportunity to contribute. |
| Consult              | ■ This is a partner step.  
                        ■ Consult your partner to get feedback on your answer.  
                        ■ Listen to the feedback from your partner.  
                        ■ Ask questions that would help you understand your partner’s feedback.  
                        ■ Carefully consider the feedback that your partner gives.  
                        ■ Take turns so that each partner has an opportunity to receive feedback. |
| Revise               | ■ This is an individual step. Work quietly.  
                        ■ Revise your work based on any problems you discovered on your own during the contribute and consult steps.  
                        ■ Decide which advice is useful and would improve your answer. Include any ideas that your partner had that you thought were good.  
                        ■ Use a different-colored pen or pencil for your revisions.  
                        ■ For any feedback that did not lead to a revision, describe why you chose not to make any changes. |

Figure 1: The consider-contribute-consult-revise (CCCR) strategy. Use these steps to complete the CCCR strategy. This strategy will help you have a clearer and more complete understanding of the concepts you learn about.
## Explanation Tool

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**Argument Tool**

**Constructing a Scientific Argument**

Decide which claim you think is best supported by the evidence and scientific reasoning. Using the criteria below and the information in the boxes you have completed, write a scientific argument that includes:

- The scientific question.
Your claim (that is best supported by evidence and reasoning)
- Relevant evidence that supports your claim
- Scientific reasoning that critiques the evidence and evaluates your claim

Critical Argument

Critique of the rebuttal
Other people might claim ....
I think the problem with this argument is....
Distribution of sticklebacks in the Kenai Peninsula (Southern Alaska). Lakes were sampled for stickleback population and the presence or absence of a pelvic spine was recorded. The circles represent the proportional amounts of sticklebacks found. Black= spine, white= no spine. Lakes are stippled, streams and rivers (solid and broken lines). Figure from Bell and Orti “Pelvic Reduction in Threespine Stickleback from Cook Inlet Lakes: Geographical Distribution and Intrapopulation Variation.” Copeia 1994(2), pg 314-325.
Figure from Bell et. al. showing locations of sampling sites, sampling sites (A–E) and isobaths (m) within Loberg Lake.

Figure from Bell et. al. "Twelve years of contemporary armor evolution in a threespine stickleback population." *Evolution*, 58(4), 2004, pp: 814-824
Relative % of stickleback population with a pelvic spine (□) versus no-spine (□) in Loberg Lake, Alaska
Data compiled from: Bell et. al. “Twelve years of contemporary armor evolution in a threespine stickleback population.”
What do you think is causing the change in the stickleback population in Loberg Lake?
Example Explanation A:

Overarching Question: What is the cause and function of the changes seen in the stickleback populations?

Question: Why did freshwater sticklebacks evolve to have no-spines?

Sticklebacks without spines have a faster growth rate, but a smaller overall size, than the sticklebacks with spines. As evidenced by the graph from Loberg Lake, populations of sticklebacks in freshwater environments evolve from high percentages of sticklebacks with spines to high percentages of sticklebacks without spines. The growth rates of sticklebacks in freshwater with no spines is 0.124 mm/day and in saltwater environment is 0.122 mm/day. The growth rate of sticklebacks with spines is 0.116 mm/day in freshwater and 0.123 in salt water. The average size of adult freshwater sticklebacks sampled in different environments are: 45 mm, 42 mm, 53 mm, 45 mm, and 40 mm. This is smaller in size than the populations of sticklebacks found in salt water. The average size of saltwater sticklebacks are: 50 mm, 60 mm, and 56 mm. The absence of the spines allow the freshwater stickleback to grow faster but their relative size is smaller, this might allow the stickleback without spines to survive better in a freshwater environment than the stickleback with the pelvic spine.
Average length of female sticklebacks sampled in 8 different locations. Samples were taken in Sweden and Finland in marine and inland populations.

Data was taken from DeFaveri and Merila “Variation in Age and Size in Fennoscandian Three-Spined Sticklebacks (Gasterosteus aculeatus)” PLOS One 8(11): e80866.

Overall growth rate of stickleback in salt water compared to freshwater conditions.

Data was taken from Barrett, Rogers, and Schulter “Enviornment specific peiotropy facilitates divergence at the ectodyspasin locus in threespine stickleback”. Evolution 63-11:2831-2837.
Example Explanation B:

Overarching Question: What is the cause and function of the changes seen in the stickleback populations?

Question: Why are not all sticklebacks small with no pelvic spine?

Sticklebacks without spines can evade predation from dragonfly larva easier but are more susceptible to being eaten by larger predatory fish. The length of the pelvic spine has been shown to increase with an increase in the number of predatory fish species that live in the same environment of the stickleback. In fish with complete spines a handling time of 30-60 seconds increases the number of escapes from 10% of the time to more 20% of the time, and more than 40% of the time when the handling time is above 60 seconds. Fish with low spines (no or short pelvic spines) handling times of 30-60 second only results in escapes 5% of the time. When handling time increases over 60 seconds the escape rate increases to 25% of the time. Dragonfly larva favor smaller sized fish and prey predominantly on fish from 15-25 mm in size. When predatory fish are present, fish with full spines are more likely to evade capture, but when there are no predatory fish present then a rapid growth rate helps to avoid predation by the dragonfly larva.

The fresh water environment provides different levels of nutrients which would favor the fast growing, no-spined sticklebacks. When dissolved calcium is above 10 mg/L in lakes only stickleback with a full pelvic spine are found. When dissolved calcium was between 2 and 4 mg/L both spined and no-spined sticklebacks are found. When dissolved calcium is at 2mg/L or below only no spined fish were present. The presence of the predatory fish did not appear to affect which populations of sticklebacks fish were found. The levels of dissolved calcium had a greater effect on the populations of sticklebacks found in lakes than the numbers of predators present.

Stop and reflect: How do explanations A and B compare to your ideas about what is causing the changes to the stickleback population in Loberg lake?
Figure 1: Length of the pelvic spine and the number of predatory fish present in the environment of a 3-spined stickleback. As the number of predatory fish increases, there is a positive association with the length of the Pelvic spine. Straight lines indicate data collected, dotted line indicate the trend in the data. Data adapted from K.B. Marchinko "Predation’s role in repeated phenotypic and genetic divergence of armor in threespine stickleback" Evolution 63-1; 127-138

Figure 2: Frequency of escapes compared to the length of time a fish is handled by a predator. As the amount of time a fish is handled increases, the more likely they are to escape the predator. This likelihood of escape increases when the length of spines are longer. Figure from T.E. Marchinko "Predator handling failures of lateral plate morphs in gasterosteus aculeatus: functional implications for the ancestral plate condition" Behavior 137: 1081-1096

Figure 3: The relationship between dissolved calcium and the abundance of predatory trout in 33 lake populations. Circles represent stickleback with short or no pelvic spines. Triangles represent stickleback with full spine. Figure from T.E. Marchinko "Predator handling failures of lateral plate morphs in gasterosteus aculeatus: functional implications for the ancestral plate condition" Behavior 137: 1081-1096
Figure 3: Stalking and capturing of a prey by a dragonfly larva. Figure from T.E. Marchinko "Spine deficiency and polymorphism in a population of Gasterosteus aculeatus: an adaptation to predators?" Can. J. Zool. Vol 58 1980

<table>
<thead>
<tr>
<th>Tank</th>
<th>15–25 mm</th>
<th>30–40 mm</th>
<th>50–60 mm</th>
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<tbody>
<tr>
<td>A</td>
<td>30</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>28</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>0</td>
<td>0</td>
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<tr>
<td>% of total</td>
<td>97.8</td>
<td>4.4</td>
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Figure 4: Predation of stickleback fish by Aeshna (dragonfly larva). Different sizes of sticklebacks were presented to dragonfly larva and the number of fish eaten were measured. Tank A, B, C represented three trials of the experiment and the experiment lasted for 25 days with fish replaced every 6 days. The author found no difference between the number of fish eaten with and without spines. Figure from T.E. Marchinko "Spine deficiency and polymorphism in a population of Gasterosteus aculeatus: an adaptation to predators?" Can. J. Zool. Vol 58 1980
Example Explanation C:

Overarching Question: What is the cause and function of the changes seen in the stickleback populations?

Question: What causes the presence or absence of the stickleback pelvic spine?

Sticklebacks that do not have spines have a change in their DNA that does not turn on the Pitx1 gene, and sticklebacks that do have spines do not have this change and Pitx1 is turned on in the pelvis. The expression of Pitx1 in the marine sticklebacks shows the gene turned on in the mouth, jaw and pelvis. Expression of Pitx1 in freshwater sticklebacks shows only expression in the mouth and jaw but not pelvis. The sequence of the switches to the Pitx1 gene in the freshwater sticklebacks showed differences in the DNA from those of the marine sticklebacks. Looking at several populations of fish, the change in the DNA switch for the Pitx1 gene was found in all fish that lost the pelvic spine. In manatees a change in the Pitx1 switch was also observed.
Figure 1: Expression of the Pitx1 gene. Fish in A, C, and D are marine samples with expression of Pitx1 in the mouth and pelvis. Green circles highlight expression in the pelvis. Fish in B, E, and F are freshwater samples with expression in the head but not the pelvis. Red circles highlight absence of expression in the pelvis. Figure from M.D. Shapiro, et al. Genetic and developmental basis of evolutionary pelvic reduction in threespine sticklebacks. Nature 428: 717-723. Correction.

Figure 2: In the marine stickleback the switches to turn on the Pix1 gene are functional and the gene is turned on in the mouth, jaw and pelvis. In the freshwater stickleback there are mutations present in the switch to turn on the gene in the pelvis and the Pitx1 gene is only turned on in the mouth and jaw. Figure from https://ncse.com/book/export/html/2585.

Figure 3: Loss of the switch that turns on Pitx1 in the pelvis occurs in many different organisms. The loss of the switch was found in freshwater stickleback species. The manatee also has the same loss of the Pitx1 switch in the pelvis and may be the reason that the manatee lost its hind limbs. Figure from M.D. Shapiro, M.A. Bell, and D.M. Kingsley. Parallel genetic origins of pelvic reduction in vertebrates. Proceedings of the National Academy of Sciences of the USA 103: 13753-13718.
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**Argument Tool**

**Question**
What is the question that you are investigating?

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| The evidence that supports this claim is... | The evidence that supports this claim is... |

**Scientific Reasoning: Evaluating the Evidence and Claim**

| Critique the quality and strength of the evidence that supports this claim. | Critique the quality and strength of the evidence that supports this claim. |

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Argument Tool

Constructing a Scientific Argument

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Scientific Argument

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