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Learning in Minnows Begins in the Egg!
An ADI Lesson in Animal Behavior and Science Practices

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Abstract

How can we help our students to learn to think like scientists and present their arguments with supporting evidence? This article presents a learning unit produced by the Animal Behavior Lab at Ball State University, including two activities that address the Science and Engineer Practices and Disciplinary Core Ideas about information processing, social behavior and adaptations at the middle and high school levels. The lessons are based on research into the learning of predator avoidance in minnows that takes place before the embryos hatch from the egg. Lessons include a group activity to simulate social learning in fish, and a student investigation using the Argument Driven Inquiry (ADI) model that has been shown to improve students critical thinking and evidence-based argumentation skills. Learners use all eight of the Practices to think about video-based stories about the research on minnow embryos, and plan the data collection for their own investigation using real videos of fish embryos. Lessons described in the article are available at no cost using links included in the article. The authors describe the activities with some background on the development of the lessons and links how to access teacher materials, student handouts, and embedded videos in the ADI unit.

Keywords: *Argument Driven Inquiry; Science Practices; Animal behavior; Middle school science; High school science*

Introduction

Imagine you are a minnow just hatched from an egg, a tiny fish trying to survive in a pond ecosystem. As you swim, you notice smells in the water that are new, and you have an idea that some might be from other animals. You notice shadows of larger things swimming above you, and your instincts tell you that some of the new smells and sights might mean danger. Your instincts also tell you that the best way to avoid danger is to sit very still among the dead leaves and aquatic plants so you are not seen. But you also need to find food, and that means moving around.

How will you know which signals your senses detect are signs of danger? When should you remain still? When is it safe to move? If you interpret the signs incorrectly, you may be eaten by other fish, large insects, birds… the dangers are too numerous to count!

This is a problem faced by many living things, especially the small ones in an environment in which there are so many predators. Instincts can tell you how to act in some situations, but when and how to react likely depends on the specific community of living things in which you are born. In order to survive, you need to learn! You need to learn to recognize danger, and you need to learn to how react to those dangers.

How animals learn these lessons, and when they learn them, is a part of the questions being investigated by the Animal Behavior Lab at Ball State University. This lab is led by Dr. Jessica Ward, and it includes graduate and undergraduate science students who conduct experiments designed to help understand how minnows learn these critical survival lessons, including research to determine if embryos learn to identify and avoid being detected by predators while still in the embryonic stages of development.

The answers to the questions explored in this lab may help us understand how more complex living things develop, including humans. What kind of learning can occur in early stages of development for mammals? How can what researchers learn about embryonic learning help us improve the survival of endangered animals like frogs and salamanders if we raise them in captivity? Do chemicals we put into streams have an impact on learning of survival behaviors in fish and other aquatic species? There are many other potential questions that can arise from this study.

The National Science Foundation is one of the

Full listing of authors and contacts can be found at the end of this article.

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organizations supporting the research done in Dr. Ward's Animal Behavior Lab. In all of their recently-funded projects, NSF encourages projects to include a "Broader Impacts" component in order to maximize the benefits of the research they support. NSF hopes these Broader Impacts elements (NSF, 2025) can help promote an expanding STEM workforce, engage the public in action based on the research results, or enhance economic competitiveness in a global market. For the Animal Behavior Lab's study on learning in fish embryos, the broader impacts initiatives include producing educational resources that encourage greater participation in STEM fields, especially among underrepresented populations. In this article, we will describe a learning unit with multiple activities designed to help middle and high school students better understand how scientific ideas are tested, retested and peer-reviewed before becoming part of the published literature. Students also learn in this lesson how to ask testable questions and plan an investigation that can lead to evidence-based inferences.

The main elements included in this unit are the "Learning to Survive" group activity and a short "Engage" activity (Bybee, 2009) that allows students to experience how young fish can learn to identify and react to predators. Learners then are introduced to the research about embryonic learning in minnows in a lesson called "Fish Go to School?" This lesson is designed using an "Argument Driven Inquiry" model (ADI Project, 2024) developed at the University of Texas. Both lessons are available on a Ball State website called the "Science Teaching Resources Integrated Design Studio" (STRIDeS, 2025) and is free for teachers to download and use in their classrooms.

Argument Driven Inquiry

Argument Driven Inquiry (ADI) is a framework for designing lessons that promote students' ability to write and talk about their ideas in a manner that emphasizes the use of argumentation from evidence (Sampson & Walker, 2012). This process is an integral part of the scientific process, and the lessons developed from this project attempt to help learners understand how new scientific ideas are formed, and why published research has a certain level of trustworthiness. Multiple research studies have demonstrated that ADI helps students improve critical thinking skills, argumentation skills, and their ability to use scientific practices (Amielia et al., 2018; Fakhriyah et al., 2021; Melta et al., 2024).

The structure of an ADI lesson has some similarities to Problem-Based Learning (Torp & Sage, 1998) in that both incorporate a framework that helps learners to consider what information they have and what information they need as they engage with a real-world problem. Both lesson structures draw from stories taken from real scientific studies or current events that relate to specific science concepts, and both encourage students to work in groups and report their ideas and conclusions to the rest of the class.

One feature that is added to the ADI framework is an emphasis on the peer review process. The lesson materials are structured in seven "Stages" (see Figure 1), and in at least three stages, students share their ideas and elicit feedback from their classmates in a peer-review process.

The ADI frame also blends well with the "Three-Dimensional Learning" model presented by the Next Generation Science Standards (NGSS Lead States, 2013). Each lesson begins by presenting students with a science "phenomenon" within which the core science ideas are embodied. As students learn about the concepts, they use the Science and Engineering Practices (SEPs) to ask questions, plan and implement investigations, present models to explain their thinking, and apply the mathematical and computational skills used to analyze and present data. They draw inferences from the evidence, and communicate their findings, justifying their claims with supporting evidence. The SEPs are an integral part of the entire ADI process, and discussion of findings offers a natural opportunity to discuss how

Figure 1. ADI Structure in Stages (Sampson & Walker, 2012)

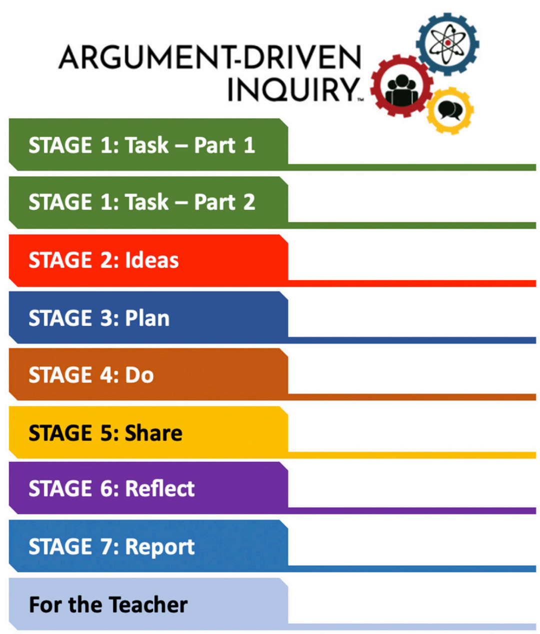


Figure 2. Standards alignment with NGSS

Science and Engineering Practices	Disciplinary Core Ideas	Crossing Concepts
1. Asking questions 2. Developing and using models **3.** Planning and carrying out investigations **4.** Analyzing and interpreting data 5. Using mathematics and computational thinking 6. Constructing explanations 7. Engaging in argument from evidence 8. Obtaining, evaluating and communicating information	**LS1.D: Information Processing** **LS2.D: Social Interactions and Group Behavior** **LS4.C: Adaptions**	**Patterns** **Cause and Effect** **Scale, Proportion & Quantity** **Stability and Change**

concepts fit with the several Crosscutting Concepts seen in the NGSS standards. Figure 2 shows a table aligning the concepts included in the activities we share in this article with the NGSS.

Teachers are likely to find the structure of ADI lessons quite familiar, while also pushing their students out of their comfort zone when they engage in peer review. This is not a common feature of most science lessons, and students often express some discomfort in evaluating each other. Still, this is an important part of the science process, and it allows students to be more metacognitive in their own use of the science practices.

Evidence of Social Learning in Embryonic Minnows

The phenomenon with which students will engage in the lessons described below is the ways in which fish learn to identify and avoid predators, both as young fish and as embryos. Normally, small fish can either hide or stay very still to avoid being seen by predators. Young fish can learn which predators to fear and how to avoid them by watching other fish. Embryonic fish, while still developing in the transparent egg, normally move about, flipping and turning inside the egg. This movement is one of the ways predators find the eggs. The only defense embryonic minnows have is to become very still and hope the predator does not notice them.

The researchers in Dr. Ward's team and others have revealed that minnows are born with an instinctive fear response to a chemical the researchers call "alarm cue" (AC) that is given off by skin cells of other minnows when they are attacked or killed. This signal tells the fish that there is a danger at hand. Embryonic fish – the ones still in the egg – have only one option to defend themselves. They freeze in place to avoid being seen. The alarm cue is small enough to pass through the porous shell of the fish egg, called the "chorion." When a minnow embryo smells the alarm cue, it stops moving. Figure 3 is a photograph of one of the embryos as seen under a microscope.

The research being conducted in Ward's lab has found that the minnow embryos can also learn to associate the alarm cue with the scent of a predator. These "predator cues" (PC) include the scent of the fish. If minnow embryos are given the alarm cue (AC) and the predator cue (PC) at the same time, they learn to recognize the PC as a signal of danger, and will respond by reducing their normal movement (Karasch & Ward, 2025). This phenomenon is an example of fish using information they detect via their senses (DCI LS1.D in the NGSS) as an adaptation to help increase their chances of survival (DCI LS4.C).

The process by which the researchers at Ball State have revealed this pattern is also an important example of how scientists develop new ideas. This lesson can teach about learning in embryonic fish, but it also serves as a model for designing experiments, controlling variables, collecting data by observing and counting, analyzing data by comparing different experimental groups, and drawing inferences from the evidence. To introduce students to this process, there are two parts to the unit plan created from the work done in the Animal Behavior Lab.

Figure 3. Minnow embryo in egg. (K. Steinberg, 2025)

"Learn to Survive" – an Engage Activity

The first of the two activities in this unit plan is "Learn to Survive." This activity is designed as an Engage activity (Bybee, 2009) to help students understand what "learning" looks like in fish, and how fish learn by social observation after they hatch, and has been refined after being tested in middle school, high school, and college classes, as well as a pair of teacher professional development workshops. This activity takes about 10-15 minutes to complete, and uses a YouTube video and printable materials available as a free download from the BSU STRIDeS website. The downloadable files include a teacher handout with instructions and standards alignment. The video presents a 4-minute video of fish in an aquarium. One of the fish species in the tank is identified as a "predator" that should be the cue to show a defense "response" behavior.

In this activity, the students are "fish," and their job is to learn how to recognize and avoid a predator. Each student is given a card (Figure 4) that identifies each person as either a "Control" fish or a "Conditioned" fish. The "Conditioned" fish know what the predator species is, and they know how to respond when they see it. In the example shown in Figure 4, the response is to "clap once" when the predator appears. The teacher guide suggests some other responses that the teacher can choose.

When the students know which kind of fish they are, the teacher projects the video on the screen or monitor in the classroom. As they watch, the "Conditioned" fish should respond (clap) each time they see the predator fish. The task for the rest of the students is to figure out which fish is the predator, and how to respond when they see it.

In our tests of this activity, we find that some learners will clap at the wrong time until they catch on to the pattern. As more members of the class "learn" when and how to respond, the learning seems to speed up, and by the end of the video, the entire class will clap when the predator appears.

There are discussion questions in the activity guide that teachers can use to help students understand how social learning (DCI LS2.D in NGSS) can help the species survive, and how terms like "control" and "conditioned" will be used when they learn more about the animal behavior study in the next part of the unit.

Figure 4. Fish cards in "Learn to Survive" activity.

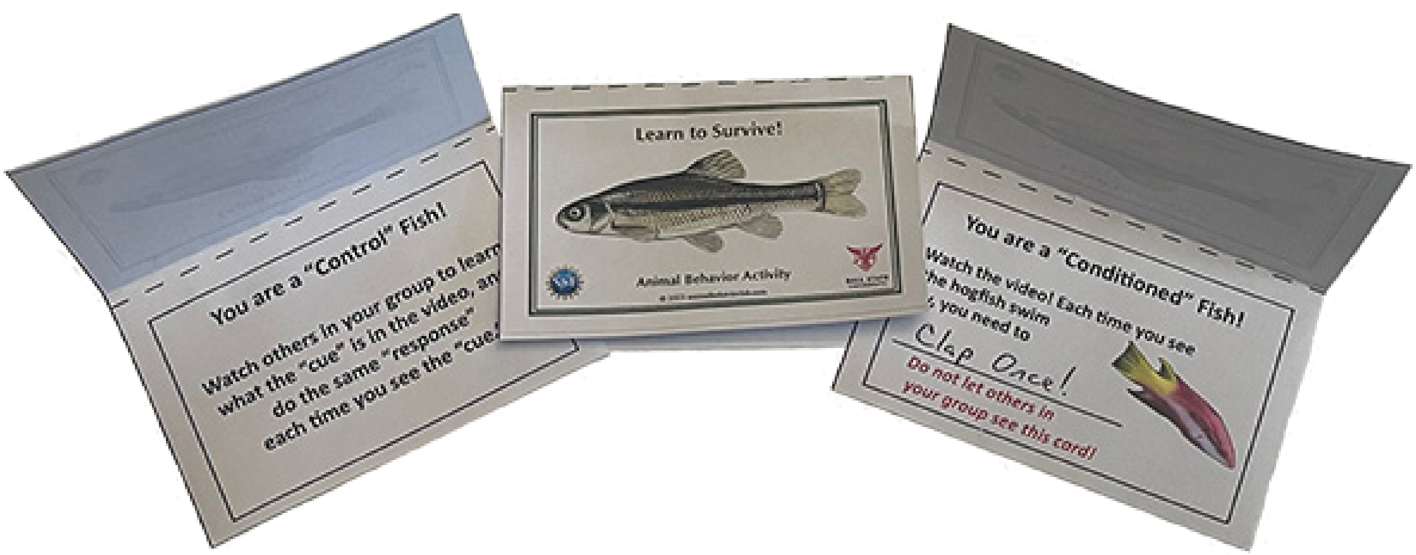


Figure 5. Video clip from "Fish Go to School?" lesson

"Fish Go to School?" Lesson

The main activity sequence in this unit is the "Fish Go to School?" ADI lesson. In this multi-day unit tested in middle school and college classrooms, students will learn about the Animal Behavior Lab's research on learning in embryonic fish, and use what they learn to plan how they will record and interpret data in their own investigation. The free downloadable PDF files with this lesson include a teacher guide and a packet of student handouts to help them proceed through the seven stages of the ADI model.

https://strides.bsu.edu/fish-go-to-school-adi-lesson/

The lesson begins by introducing students to the phenomenon of learning in fish embryos. This involves a short paragraph to introduce the topic, and a short video in which the researchers give a brief introduction to their work (Figure 5). The students are then prompted to write what they noticed in the video, and what they want to know more about. This step is similar to the KWL charts used in many other science lessons.

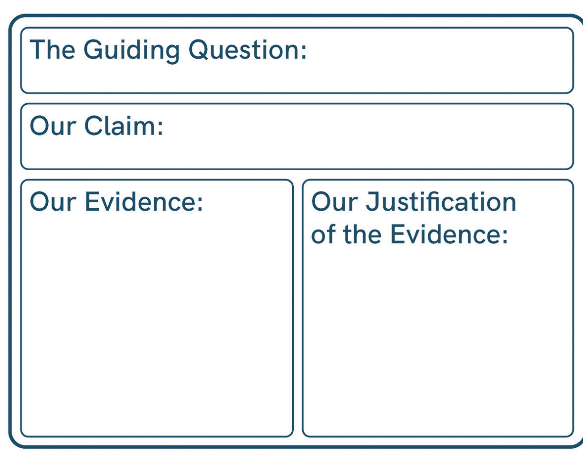
After discussing their ideas about the first video, students are then shown a second video with more information about how fish behave when they sense danger, and how minnows' behavior changes if they learn to associate the predator cue with the instinctive response to danger. Students again write their ideas and reflect on how the "core ideas" from the videos will be used in designing their own investigation. Among these core ideas is the explanation of the change in the movement of the embryos when they sense danger. This change in movement can be observed and counted to measure the ability of embryos to associate Predator Cue with the alarm response.

These initial videos and reflections make up **Stage 1: Task** and **Stage 2: Ideas** (See Figure 1). In **Stage 3: Plan,** the Student Packet provides a template to help students write a plan for how they will collect data from a video showing "conditioned" embryos before and after introducing Predator Cue (PC) to the water. Their goal is to plan a way to determine if the embryos have learned to associate PC with the alarm response. The investigation plan is then shared with other students to collect feedback, followed by prompts to revise the plan according to that feedback. Once the plan is ready, groups show their plans to the teacher to receive confirmation that they are ready to proceed.

Stage 4: Do is the process of collecting evidence. In this lesson, the students are told about a group of embryos that were introduced to both AC and PC by the research team at Ball State. They will observe two short video clips (1 minute for each) of a single group of embryos. The first video shows the embryos before the PC is added. The second clip shows the same embryos after PC was added to the water. The plans developed by students should include how they will count and record data. The Stage 4 templates include a space to create a graph of the results to display patterns and guide the inferences made from the data.

Stage 5: Share is another opportunity to communicate findings and elicit peer review. Students are given a template to create a "Draft Argument Board," a way to display an early version of their conclusions in a "Claim, Evidence, Reasoning" format (Figure 6). The teacher guide suggests using white boards for this, but tablets, a poster, or a PowerPoint slide could also serve as the Argument Board. Students can then present their conclusions to the class and receive another round of feedback. They are also prompted to reflect on how the feedback is used to improve their argument.

Figure 6. Argument Board template



Stage 6: Reflect is a phase in which student groups can discuss and write about how they could improve their investigation. This is an excellent opportunity to discuss sample size, sources of error, revise procedures, and perhaps ask questions that could take their understanding to a new level. Stage 6 represents both a form of self-assessment and a chance to practice metacognitive reasoning, both of which are important skills for students to develop.

Stage 7: Report involves creating a final summary of the study – the "lab report" with an additional peer-review component. The Student Packet begins with sentence starters to prompt students' writing of their report. The ADI Project has several report templates that vary in structure to fit different types of experiments. The template our team chose was selected because it fits the structure of the fish embryo experiment. Once each group has written their report, they share it with another group who provides written feedback in a Peer Review Guide (Figure 7). This guide also serves as the Teacher Rubric, and is divided into three sections to address the major elements of the report: Introduction, Method, Argument. (See Appendix to view the Rubric.) There is also a space for the students to describe how they used the feedback to revise the report. Only after this review and revision process do students submit their report to the teacher to be graded. Teachers can modify the report template and the review process to fit their students' specific needs.

Figure 7. ADI Peer Review Guide (see Appendix)

Fish Go To School? **Student Packet**

Report Peer Review Guide and Teacher Scoring Rubric

Report by ______ Project ID #

Author: Did the reviewers do a good job? 1 2 3 4 5 Rate the quality of review

Reviewed By: ______ Reviewer ID # ______ Reviewer ID # ______ Reviewer ID #

Look at the Introduction. Do you think:	Reviewer Rating			Teacher Score
1. There is a good overview of the phenomenon?	No	Somewhat	Yes	0 1 2
2. The task and guiding question are clear?	No	Somewhat	Yes	0 1 2
3. It is clear why it is important to complete the task?	No	Somewhat	Yes	0 1 2
Reviewers: Please explain how the author could improve this part of the report.	**Author:** What changes did you make to your report based on the feedback from reviewer?			

Look at the Method. Do you think:	Reviewer Rating			Teacher Score
4. There is a good overview of the phenomenon?	No	Somewhat	Yes	0 1 2
5. The methods make sense for the investigation?	No	Somewhat	Yes	0 1 2
6. It is clear enough to allow others to do the same?	No	Somewhat	Yes	0 1 2
Reviewers: Please explain how the author could improve this part of the report.	**Author:** What changes did you make to your report based on the feedback from reviewer?			

The ADI framework provides teachers with a structure to help students experience elements of the science process often left out of other science lessons. Most of the good hands-on science investigations involve predicting and hypothesizing, designing and carrying out experiments, analyzing data and communicating results, but few offer a structure to include peer review as part of the argumentation process. This is an integral part of the work of professional scientists, embodied by collaborations within a research group, conference presentations, review of manuscripts submitted for publication, and the reiterative process of review by other researchers. Understanding how scientific ideas are vetted through this review process is an important way in which educators may be able to impact their students' trust in science.

One of the guiding principles of the design of the unit is a statement presented to the science education majors at Ball State: "If we want our students to THINK like scientists, we need to have them DO what scientists do." The lesson also provides an opportunity for students to see an example of real scientists at work, and to participate in doing science in ways that emulate the work of real scientists.

Access to the Lesson Plan Materials

Both activities described above are available for teachers to download and use for free. The files for "Learn to Survive" and "Fish Go to School?" are available on the BSU STRIDeS website, along with other free resources for science educators. The links on the next page take you to the STRIDeS page, and to the specific activities within the site.

Acknowledgements

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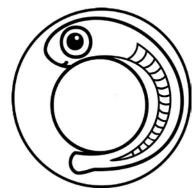
STRIDeS

STRIDeS website

https://strides.bsu.edu/



Learn to Survive

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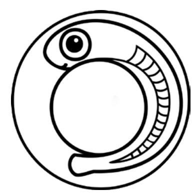

Fish Go To School?

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Appendix

Fish Go to School

Report Peer Review Guide and Teacher Scoring Rubric

Report by ____________________ Project ID #

Author: Did the reviewers do a good job? 1 2 3 4 5 Rate the quality of review

Reviewed By: ____________________ Reviewer ID # ____________________ Reviewer ID # ____________________ Reviewer ID #

Look at the Introduction. Do you think:	Reviewer Rating			Teacher Score
1. There is a good overview of the phenomenon?	☐ No	☐ Somewhat	☐ Yes	0 1 2
2. The task and guiding question are clear?	☐ No	☐ Somewhat	☐ Yes	0 1 2
3. It is clear why it is important to complete the task?	☐ No	☐ Somewhat	☐ Yes	0 1 2
Reviewers: Please explain how the author could improve this part of the report.	**Author:** What changes did you make to your report based on the feedback from reviewer?			

Look at the Method. Do you think:	Reviewer Rating			Teacher Score
4. There is a good overview of the phenomenon?	☐ No	☐ Somewhat	☐ Yes	0 1 2
5. The methods make sense for the investigation?	☐ No	☐ Somewhat	☐ Yes	0 1 2
6. It is clear enough to allow others to do the same?	☐ No	☐ Somewhat	☐ Yes	0 1 2
Reviewers: Please explain how the author could improve this part of the report.	**Author:** What changes did you make to your report based on the feedback from reviewer?			

Look at the Argument. Do you think:	Reviewer Rating			Teacher Score
7. There is a clear and reasonable claim?	☐ No	☐ Somewhat	☐ Yes	0 1 2
8. The analysis info is clear and supports the claim?	☐ No	☐ Somewhat	☐ Yes	0 1 2
9. The report justifies the claim and evidence?	☐ No	☐ Somewhat	☐ Yes	0 1 2
Reviewers: Please explain how the author could improve this part of the report.	**Author:** What changes did you make to your report based on the feedback from reviewer?			