THE PATTERNS APPROACH

ENGAGING FRESHMEN IN THE PRACTICES OF SCIENCE

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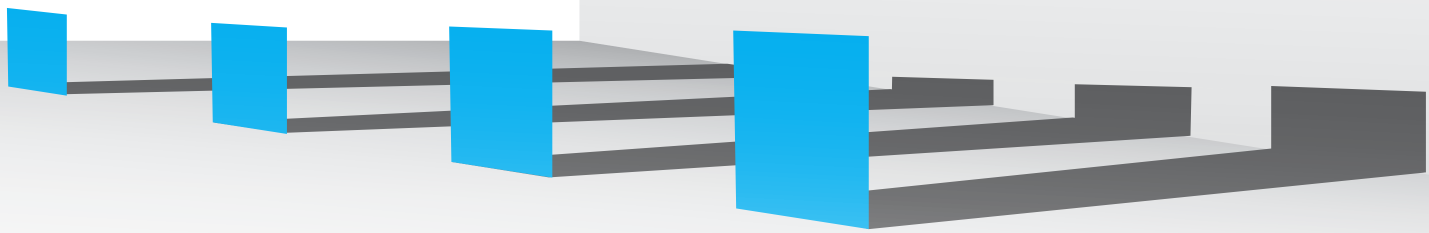


A narrow focus on content alone has the unfortunate consequence of leaving students with naive conceptions of the nature of scientific inquiry and the impression that science is simply a body of isolated facts. —NRC 2012, p. 41

Many high school physics courses have deemphasized mathematics, which has changed the nature and role of the inquiry experiments in them. This article lays out an approach built upon an introductory unit, "Patterns in Nature," which aims to engage students in constructing their understanding of physics through contextualizing and enhancing their mathematics skills. The unit focuses on four common patterns: linear, quadratic, inverse, and inverse square.

Aligning with *A Framework for K–12 Science Education* (NRC 2012), this unit teaches students to make predictions, plan and conduct experiments, collect data, analyze the results, argue from evidence, and evaluate conclusions. Harnessing their own experiences, students learn the value of evidence-based reasoning and data-informed decision making.

I expect I am like most physics teachers: I want my students to not only learn the laws and theories that describe and explain the natural world but also to understand and participate in the process that builds this knowledge and helps students see themselves as scientists. Students often approach science classes the same way they approach vocabulary lessons, memorizing as much as they can so they can ace the test. It's no wonder that few students choose to major in scientific and technical fields.

One solution is "physics first," in which students take a physics class as freshmen, and then chemistry and biology, respectively. As the most concrete of sciences, physics can provide a platform for the unobservable interactions between atoms and molecules. However, first-year physics courses often focus on concepts without math or include math but follow a pedagogical method in which students learn a formula and then practice applying it. In this deductive approach, students learn that if they choose the right formula and chug through the math, they'll be all right.

A Framework for K–12 Science Education (NRC 2012) calls for eight essential practices that help students develop science and engineering practices. Building on these practices, I developed a unit—Patterns in Nature—that uses an inductive approach to build a foundation and engage freshmen in scientific practices throughout a physics course. Students start with their personal ideas and curiosity about the world and then make predictions. They plan and conduct experiments, collect data, figure out a pattern that relates the variables in their experiments, and analyze the results—arguing from evidence, evaluating, and modifying their initial models.

The Patterns in Nature unit not only introduces students to important practices but also affects their understanding of what physics—and science in general—are all about. I emphasize that science is about being systematic and thoughtful in finding patterns in the world. This leads to the unifying question: "How can we discover and use patterns in nature to predict the future or understand the past?"

Patterns in Nature overview

After a brief introduction to asking good science questions, identifying variables, reading instruments, reporting error, and graphing with data collection software, students conduct anchoring experiments that contextualize the linear, quadratic, inverse, and inverse square functions and demonstrate the predictive power of patterns. (**Note:** I add exponential and sinusoidal patterns to my International Baccalaureate [IB] physics course.) Later, when students encounter these patterns in different contexts, in this course or others, they recognize them as familiar mathematical relationships.

Each experiment follows a similar structure. First, students make a prediction. Next, they design and carry out an independent investigation, collect and analyze the data, make sense of the pattern, and craft a conclusion. Finally, they make a data-informed prediction and run the experiment again to compare the accuracy of their low-evidence guess with their data-informed prediction. This recurring structure (Figure 1) contextualizes the investigation and allows the class to answer a unifying question for a major concept we investigate throughout the year. I provide a lot of scaffolding in this initial experiment and then taper off over the course of the remaining experiments.

Building on previous research

Although Patterns in Nature is an original unit, the Patterns Approach is not entirely new. Curricula such as "Modeling Instruction" (Wells, Hestenes, and Swackhamer 1995) and "Investigative Science Learning Environment" (ISLE) (Etkina and Van Heuvelen 2001) take a similar approach: Teachers use multiple representations to make sense of student-designed experiments, apply those understandings to novel situations and problems, and then discuss how they know what they know (Hestenes 1987; Karelina and Etkina 2007).

The Patterns Approach differs in two important ways. First, it places even greater emphasis on comparing and contrasting low evidence–based to high evidence–based predictions, including explicit discussions of confidence and uncertainty. Second, it explicitly integrates physics and mathematics: Students reason about relationships of variables in terms of mathematical patterns.

Patterns approach steps

1. *Guess a reasonable answer to teacher's prompt.* For example, in the first experiment, student groups predict how far a spring will stretch when they hang a given weight on the end. They make initial guesses, establishing low-evidence predictions and setting baselines for later comparison with their scientific, data-informed predictions.

2. *Create focused research question and hypothesis.* I guide students to sketch a graph and plot the "initial guess" data point. Next, I encourage them to use proportional reasoning in thought experiments to create hypothetical data points. Tracing the pattern that emerges, students record the relationships they hypothesize to exist between the independent and dependent variables. For example, in the case of the spring and weight, students create graphs that represent their mental models for how the spring stretches using different weights.

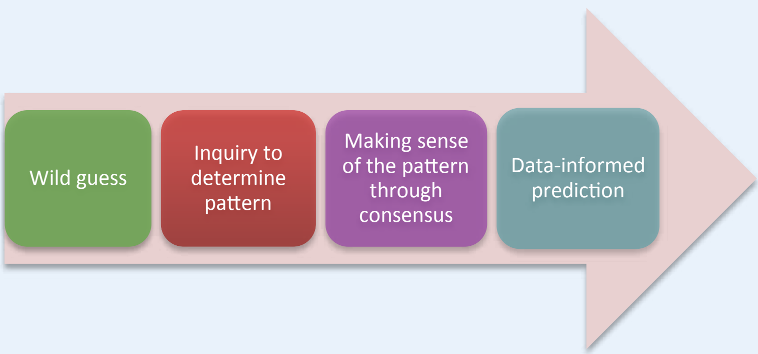
3. *Design method for data collection.* Students work in teams to think critically about how they will measure data to answer their questions. Teachers can often use students' questions from the initial prompt to inform them of what they need to control or how they want to measure.

4. *Collect and process data into multiple representations.* Students collect data using the methods they designed in the previous step. The Patterns Approach emphasizes students' abilities to collect and recognize appropriate data ranges, evaluate a reasonable pattern considering uncertainty, and represent the pattern in multiple ways.

A note on estimating error. Within this framework, there is an increased need for accurate accounting of error. Using overly simplistic rules for uncertainty can potentially inhibit students' abilities to determine the correct pattern and make accurate predictions based on their data; high school students, in particular, often

FIGURE 1

Path to a better prediction.



have other sources of error beyond instrumental precision. However, with accurate error bars and well-chosen experiments, students can reliably produce successful results.

5. *Find the line of best fit.* Students enter their data into data collection software and use the curve-fitting feature to find the simplest best-fit lines that intersect all of the error bars. (**Note:** This method prevents students from using best-fit lines that have no applicable physical interpretation.) Later in the course, students often fit a data set with either the linear and quadratic or inverse and inverse square patterns, using evidence-based reasoning within their lab groups to determine why one pattern makes more sense than another.

6. *Build consensus around a pattern's meaning.* In this step, each student group uses a slightly different experimental setup. For example, in an experiment involving springs, groups use springs with different amounts of "springiness" or spring constants. As a result, each group has a linear pattern with a differing slope that they display graphically and mathematically on 2' × 2' whiteboards. Student groups then look for similarities and differences in each other's graphs and mathematical models. They take turns explaining their reasoning behind their patterns, critiquing each other's explanations until the class reaches a consensus. During this time, students explicitly discuss the physical interpretation of the slope of the best-fit line and any other constants or coefficients in the model.

7. *Craft an evidence-based line of reasoning.* The conclusion has two components: students' rationale for their models and their data-informed predictions. The conclusions are initially highly structured. Students cite their data, explicitly state the patterns they think exist between the variables, present a mathematical model of the system's behavior, and make a prediction.

8. *Communicate a reasoned data-informed prediction with confidence assessment.* As part of their conclusions, students consider whether their best-fit lines meaningfully capture their data and how confidently they can extrapolate that best-fit line to the predicted value. As a class, at the end of the spring experiment they create a grid (Figure 2) that they use throughout the year to guide their reasoning about their confidence assessment. This grid is naturally created when students realize the prediction is beyond the range the students tested. Some of them wonder if the pattern will hold; after they predict, we sacrifice a linear spring by hanging more and more mass until the stretch becomes nonlinear and even breaks. This activity helps the students recognize that the linear pattern is only accurate for a certain range of mass hung. They learn that if they want better predictions or higher confidence, they must take better data or a broader range of data. Further, they understand that scientists can often refine models' limitations with additional data.

9. *Testing initial prompt and reflecting on the process of science.* Testing exposes to students why scientists prefer evidence-based reasoning to reasoning based on low or no evidence. By repeatedly comparing and contrasting the predictive power of initial guesses with pattern-based, data-informed predictions, students build strong scientific identities, reinforcing their confidence in their own predictions in a straightforward, understandable way.

FIGURE 2

Assessing confidence in a prediction.

The following is an example of a table created to help students determine the appropriate level of confidence in data-informed predictions.

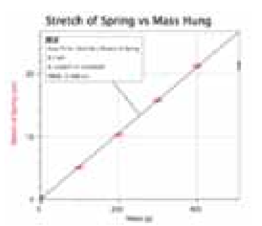
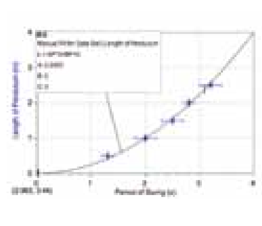
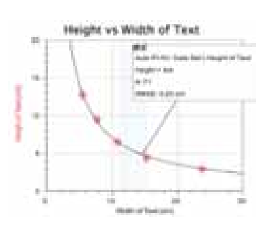
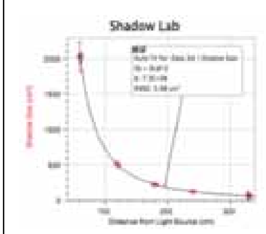
Considerations for assessing the confidence in a prediction	Predicted value is within the data range	Predicted value is near the data range	Predicted value is far from the data range
The best-fit line is near the center of nearly all the data points.	High	Medium–high	Medium
The best-fit line is near the edges of many of the data points.	Medium–high	Medium	Medium–low
There may be new physics to consider so the best-fit line may no longer apply.	Medium–low	Low	Very low

The Patterns Approach as a scientific experience

The defining feature of the Patterns Approach is that it helps students see themselves as scientists as they generate research questions, design experiments, collect data, identify patterns, and use those patterns to successfully predict future data points—just as physicists do (Karelina and Etkina 2007; Van Heuvelen 1991). Anchoring experiments (Figure 3) demonstrate how systems exhibit behavioral patterns and explore how representing these patterns offers varying ways of visualizing and understanding the pattern (Larkin et al. 1980). Students use multiple repre-

FIGURE 3

Anchoring experiences and multiple representations for the four mathematical patterns.

Pattern	Linear	Quadratic	Inverse	Inverse square
Research question.	How does the mass hung on the spring affect how much it stretches?	How does the length of a pendulum affect its period?	How does reformatting the width of a paragraph affect its height?	How does the distance a note card is from a light source affect the size of shadow it casts?
Materials needed per setup.	Ring stand, linear spring, masses, ruler.	String, masses for bobs, metersticks, stopwatch, protractor.	Printout of same paragraph with reformatted widths, ruler.	Light source, note card, screen or wall, metersticks.
Minimalist prompt for the wild guess and data-informed prediction.	How far will this spring stretch when this chunk of metal is hung?	How long will it take this pendulum to make one swing back and forth?	What will the height of the following orally read paragraph be when printed 33.5 cm wide?	What size shadow will this note card make when placed here?
Graphic representation.				
Mathematical model.	Stretch = $0.12 \frac{cm}{g}$ * mass	Length = $0.25 \frac{m}{s^2}$ *Period^2	Height $= \frac{86cm^2}{width}$	Shadow Size $= \frac{140000cm^4}{(distance)^2}$
Visual representation.	mass hung → mass hung stretch → stretch	period → period length → length	width → width height → height	distance → distance size → size
The pattern described in words.	If you double the mass hung, the stretch doubles.	To double the period, you must quadruple the length.	If you double the width, the height will be halved.	If you double the distance, the size of the shadow will be quartered.

sentations (e.g., graphical, visual, verbal, mathematical) to increase the access points where they can first understand and apply the patterns.

Patterns in Nature consists of four experiments:

1. Students hang five different masses from a spring and measure how much it stretches.
2. Students measure five different lengths of a pendulum and time how long each length takes to complete one full swing.
3. Students reformat a paragraph into five different widths and then measure the effect on the paragraph's height.
4. Students use a square note card to cast a shadow at five different distances from a light source and measure each distance's effect on the size of the shadow.

Data-informed predictions

I have found that starting with an initial guess and ending with a data-informed prediction is an effective hook. Students hope their initial guesses are close but then almost always take even greater pleasure if their data-informed predictions are accurate. The second experiment, when students swing the 5 m pendulum, always elicits a few cheers and celebratory fist pumps when students come close to accurately predicting the swing time. Further, students receive feedback in a visual, understandable way.

By building competency with each of the four patterns, the Patterns Approach provides anchoring experiences that we continually return to as we apply them to the new physics concepts during the remainder of the course. This increased fluency within the patterns and between representations—a valuable science skill in its own right—allows students to achieve success as they create more entry points to solving a problem (Rosengrant, Etkina, and Van Heuvelen 2007).

Students bring a wealth of experiences related to many of the physics concepts we cover. By explicitly discussing uncertainty and limitations and harnessing students' prior experiences, the Patterns Approach makes physics feel far more concrete and understandable than a typical curriculum. Students learn that formulas are simply shorthand for connecting past empirical observations to the current problem. They also learn to frame many critical questions that have natural, understandable answers. With little guidance, students can determine for themselves that an additional data point taken far from their data range can lead them to a more accurate pattern relationship. Further, they often invoke the meaning of the physical interpretation of a line's slope to reason what pattern makes sense.

Conclusion

The Patterns Approach is effective in preparing students to recognize patterns, describe them using multiple representations, craft lines of evidence-based reasoning around them, and use them to make data-informed predictions. These skills are necessary if students are to achieve the Next Generation Science Standards and many of the mathematical practices discussed in the Common Core before they graduate from high school. In my experience, the Patterns Approach is a promising means of fulfilling our commitment to teach the value of evidence-based reasoning and data-informed decision making. ■

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