What story does your experiment tell? Teaching science students to craft organized and coherent introductions

The Introduction in a scientific paper is tricky to get right: students have to explain content material that is often new to them while at the same time introduce and support a novel research question that goes beyond what is already known. To write a good Introduction, students need to feel comfortable performing three higher-order thinking skills: a) synthesizing primary literature, b) identifying unanswered questions, and c) communicating a new idea that can fill a knowledge gap. You may consider simplifying this task for your students by adopting the following framework for writing an Introduction, or modify this framework to suit your class's needs.

Three components of a good Introduction

Background Information

- *Ideal characteristics*:
  - **Synthesizes a broad area of research** relevant to this study
  - Provides context and motivation for rationale, hypothesis
- *Common issues*:
  - Could be infinitely long: what is essential?
  - No identification of broad question

Rationale

- *Ideal characteristics*:
  - Illustrates a mechanism connecting independent and dependent variables used in this study
  - **Identifies a knowledge gap**: something we don't yet know
- *Common issues*:
  - Not enough detail provided to truly understand system
  - Supporting literature is listed without integration

Hypothesis

- *Ideal characteristics*:
  - **Communicates a question** that can be tested in the scope of this study
  - Clearly demonstrates a relationship between two variables
- *Common issues*:
  - Hypothesis is too broad to actually be testable
  - No anticipated direction of relationship between variables

Practice identifying the components of a good Introduction: Strip-chart exercise

Assemble into small groups (3-4 students per group). Each group will receive an Introduction section from a published paper, but the sentences/paragraphs will be out of order. Your task is to re-organize your group's introduction in a way that makes sense to you, and to explain your reasoning.

Reflection: What strategy did you use to re-assemble this Introduction? How would you teach your students (who are NOT professional scientists) to do this?

Other tools for teaching students to write an Introduction

Science writing is hard to master, so don't be discouraged if students don't immediately grasp these principles. However, with enough reinforcement, students can make great progress in your course. Here are some techniques you can sprinkle into class throughout the semester to reinforce high-quality Introduction writing.

1) *Model good introductions*

Find either a) an excellent (but attainable) student paper from a previous semester or b) a relevant (but accessible) published paper. Have students read the model paper and highlight the three components (background, rationale, hypothesis).

Some possible discussion questions:

- How did you identify each section?
- How long was each section? Why did the author choose to do this?
- Did you notice any similarities or differences between this paper and your own writing?

2) *Student-to-student interactions*

In my experience, students can learn a lot from each other in a well-structured, positive classroom. Once you've introduced a common vocabulary (i.e., rubric) about science writing, have pairs of students email each other their drafts 24-48 hours before class, and give the students 10-15 minutes to share their assessment of their partner's work.

NOTE: I strongly recommend making sure that you request a marked-up version of each paper, as this will help you determine if students are taking the assignment seriously.

Some possible discussion questions:

- Was your partner's background information section too broad, too narrow, or just right?
- What was your peer review partner's hypothesis? How did you know this?

3) *Individual conferences*

Meeting individually with students early in the semester can pay dividends. It can be a good idea to have a list of tasks or questions for students to complete before this meeting, such as asking them to highlight their background, rationale, and hypothesis (similar to 1, above).

Some possible discussion questions:

- Which part of the Introduction was trickiest to write? Why?
- What is one critical piece of background information your audience needs to know?
- In one sentence, how does X (independent variable) effect Y (dependent variable)?

4) *Providing a framework*

Some students may benefit from a more direct paragraph-by-paragraph roadmap of a good introduction. Consider sharing a common framework early in the semester (e.g., the hourglass heuristic or the three components on Page 1) and discussing its importance.

Some possible discussion questions:

- Why do scientific papers have a common structure? How does this help you as a reader?
- How can you effectively transition from background, to rationale, to hypothesis?

Reflection: How might you use these activities in your own class? Are there other ideas that we haven't discussed that would also work well?

Evaluating Student Writing Samples

Below, you will find Introductions from three student research proposals. Read each Introduction and evaluate it: try to identify the hypothesis, rationale, background information. Score each student (1-3) for each student on the following categories. If you could only provide a single comment for students, what would you want to tell them?

Global concerns	Hermione Granger	Neville Longbottom	Luna Lovegood
Background Information: • Identify a broad question or body of research • Clarify the importance of the study	Score: 1 2 3 Strengths: Improvement:	Score: 1 2 3 Strengths: Improvement:	Score: 1 2 3 Strengths: Improvement:
Rationale: • Mechanistically connects independent/dependent variables • Clearly states a knowledge gap	Score: 1 2 3 Strengths: Improvement:	Score: 1 2 3 Strengths: Improvement:	Score: 1 2 3 Strengths: Improvement:
Hypothesis: • Clearly, concisely stated at the end of Introduction • Shows a direction between independent/dependent variables	Score: 1 2 3 Strengths: Improvement:	Score: 1 2 3 Strengths: Improvement:	Score: 1 2 3 Strengths: Improvement:
Local concerns (Spelling, grammar, etc.)			

Sample Research Proposal: Hermione Granger

In the upcoming month (October 2018) the Biocore Prairie will be transitioning into a radiant color scheme of purple and white flowers. These flowers share the same blooming season, and will be relatively the same age, yet they will be competing to be pollinated and ensure that their genes survive. One main pollinator, that includes multiple species, is the bee. Bees and flowers interact in a mutualistic relationship that ensures each other's survival. However, with such a vast choice, bees cannot manage to pollinate every flower. Instead, they selectively choose flowers on certain facets they have previously observed, with the hopes of choosing the optimal flower with a great amount of nectar. Although there is speculation in the science community, many researchers believe that one significant indicator that bees use is color. In this manipulative experiment involving Asters, my group will test whether or not color preference exists. We believe that when given the choice, more bees will land on purple Asters than white Asters. To achieve this, fake Asters will be created and placed in the Biocore prairie; we will count how many bees land on each color.

Bees utilize color to choose the best flower in a tested process classified as flower syndrome, (Gumbert, 2010). When flying, bees are overloaded with information, so to combat this issue they rely on instinct and their memory to pick flowers. The bees will choose the optimal color by previous experiences. If a certain color has repetitive success, the bee will be trained to expect a better reward from that color, and they will continue to pollinate that specific color..This adaptation is efficient since they are making a fast, but educated selection, (Chittka, 2006). Bees do not randomly select flowers because they risk the chance of receiving no food for their effort, instead they hope to optimize the amount of sucrose they recieve with as little effort as possible. A bee will adapt this training at different rates with different colors, with the fastest rate for training being correlated with the color purple, (Gumbert, 2010). It is unknown if there is any connection between flower color and pollen content. However, the faster rate for purple flowers could be associated with the idea that purple is the easiest color for a bee to see, (bee's blue). Purple has a sharp contrast with the bee's vision, so it would require less effort to trigger memories. I assume that the concept would be similar to humans, where the more invested something is with another object, the less time and energy it takes to process the memory. Then, the reason why purple is the easiest color to see is because of the anatomy of a bee's eyes. Bees have exemplary eyesight that is known as trichromatic vision, which has three photoreceptors: blue, green, and ultraviolet. Studies have found that bees' blue photoreceptors are more stimulated by the color blue, which encompasses a range of wavelengths, around 400-420 nm, (Ostroverkhova, 2018). The color violet has a wavelength of 410 nm, which means that bees view the color as blue (Gumbert, 2000). When a bee's blue photoreceptor is stimulated by a color, this means that they are more attracted to the color (the green photoreceptor can also be excited, but it does not lead to the same attraction), (Ostroverkhova, 2018). This extra attention the color purple receives due to its optimal wavelength could attract bees to purple Asters over white Asters, and with mild success, the bees would continue this trend because of bee's reliance on memory to choose which flowers to pollinate.

Sample Research Proposal: Neville Longbottom

Wild and prescribed fires are a natural and necessary phenomenon in the prairie environment. Although fire is known to be useful to prairie wildlife, it is unknown whether fire directly correlates to an increase in plant and/or grass production. *Bouteloua curtipendula* (sideoats grama) is a perennial warm-season grass found in the Biocore Prairie with basal growing leaves, deep roots, and short and scaly rhizomes (Kilian, 2016). Rhizomes are underground, horizontally growing stems that have the ability to send shoots upward to allow another plant of that species to start growing. *B. curtipendula* are adapted to growing in drained sandy and clayey soils and are drought tolerant (Kilian, 2016). In addition, sideoats grama are moderately tolerant to wildfires in its dormant state (Kilian, 2016). Because of its sod-forming ability, sideoats grama acts as erosion control when associated with other plants and are competitive against weeds (Kilian, 2016). *B. curtipendula* had significantly greater temporal stability and drought resilience when compared to other bunchgrasses and lawn grasses (Castellano and Ansley, 2006). More specifically to this research, fires appear to enhance *B. curtipendula*'s stability and resilience for future fire (Castellano and Ansley, 2006).

Bouteloua curtipendula's main mechanism for reproduction is through its rhizomes just beneath the soil. Many species in prairies and grasslands require signals such as heat to cue seedling establishment to the favorable post-fire conditions (Schwilk and Zavala, 2012). We are assuming that fire stimulates the rhizomes just beneath the soil and causes an increase in production of *B. curtipendula*. We believe that because *B. curtipendula* is fire tolerant in its dormant state and because the leaves as basal, that the grass does not have difficulty growing after a frequent fire and that fire will in fact increase the number of *B. curtipendula* (Kilian, 2016). Biomass increases following fire are attributed to increased light availability to axillary buds at the plant base (Rideout-Hanak et al. 2011). It has also been reported that grass canopy removal, or the burning of forbs, activates new growth because of the newly available nutrients for the soil and roots (Rideout-Hanzak et al 2011). Burning can lead to increased soil temperatures, which may suppress growth of competitors and give rise to more *B. curtipendula* production (Rideout-Hanzak et al. 2011). No studies have been done on the effect of fire on *B. curtipendula* reproduction and what post-fire condition attributes to increased abundance. There also has not been a study done on the Biocore prairie if there is more *B. curtipendula* grass in the unburned or recently burned sections of Area 3.

We hypothesized that there will be a higher number of *Bouteloua curtipendula* bunches in the recently burned sections than in the unburned sections of Area 3 in the Biocore Prairie. Our approach will be to examine transects in the unburned and burned sections in Area 3 of the Biocore prairie and to count the number of bunches of *B. curtipendula* and compare the average of bunches to determine which section has the most.

Sample Research Proposal: Luna Lovegood

Bees are an essential part of the pollination process. Bees help shape their environment, including the plants in an area, their abundance, and their location. When looking at the prairie, you see a variety of vibrant colors no matter the time of season. Around these flowers, there are a variety of pollinators spreading the seeds to each of these plants. All of these flowers are surviving in their landscape and becoming pollinated even though they vary a lot to the human eye, possibly making one color more appealing than the other. This idea proposed the question, if the human eye has a major preference for flower colors, do bees, one of the most important pollinators on the prairie, also have a color preference? This brought up the idea that the bee's eye anatomy is much different than that of humans, which consequently lead to the experimental question: can we find the color preference of bees based on the human light spectrum?

"Bees have trichromatic colour vision with three different photoreceptor classes maximally sensitive in ultraviolet (UV), blue and green wavelengths" (Peitsch et al. 1992). In the late-blooming season, purple and white flowers are most common in our testing area, area two of the Biocore Prairie. While looking at these colors, it is important to remember that purple is a mix of the two primary colors red and blue, where blue is one of the bee's main visual colors, whereas white is the absence of color. Due to the eye structure and function of the bees, we hypothesize that bees will preferentially pollinate purple artificial flowers more than white artificial flowers. We will test this hypothesis by creating artificial flowers and placing them into the Biocore prairie to see how many bees visit each color flower.