

Descriptive Account

Introductory Biology Labs...They Just Aren't Sexy Enough!

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Abstract

The typical introductory biology curriculum includes the nature of science, evolution and genetics. Laboratory activities are designed to engage students in typical subject areas ranging from cell biology and physiology, to ecology and evolution. There are few, if any, laboratory classes exploring the biology and evolution of human sexual behaviour. Contemporary research in sperm competition provides a template for engaging students in a 'sexy' subject at a practical level. We describe and evaluate a laboratory exercise in which students develop and test simple hypotheses about sperm competition in humans. This activity encourages students to think about the nature of science, while they design meaningful experiments in the evolution of human mating systems. Post-laboratory assessment revealed that this exercise was successful in meeting its stated goals, engaging students, stimulating discussion and encouraging thoughtful critique.

Keywords: sperm competition, introductory biology, sexual selection, evolution, process of science, laboratory activity

Introduction

Numerous journal articles, books (e.g., Biological Sciences Curriculum Study 2009) and websites (e.g., www.biologycorner.com, http://www.aibs.org/education/teaching_resources.html) are dedicated to techniques for teaching the nature of science, evolution, and genetics in the college-level introductory biology curriculum. Adams (2009) provides a review of laboratory activities designed to engage students in meaningful activities as they learn about the nature of science; examples range from those in cell biology and physiology to ecology and evolution. However, few (if any) authors have focused on strategies for teaching about sex, a topic that engages most of us, intellectually and personally and considered 'as ideal fodder' for introductory-biology educators (Hagay and Baram-Tsabari, 2010). Here we present a laboratory exercise for discussing sperm competition in a way that encourages students to think about evolution and the nature of science in general, while they design meaningful experiments in the evolution of human mating.

Sperm competition in the curriculum

Sperm competition, defined as the competition between sperm of rival males to successfully inseminate the eggs of a polyandrous female, has led to a suite of anatomical, molecular and behavioral adaptations in myriad organisms (for a review see Birkhead and Pizzari, 2002). These adaptations range from gamete-level interactions described for cichlid fishes, passerine birds and turkeys (Fitzpatrick *et al.*, 2009, Kleven *et al.*, 2008, Donaghue, 1999), to the cryptic female-choice machinations of sand lizards (Olsson *et al.*, 1996) and the dramatic sperm-gouging devices of damselflies (Hosken and Stockley, 2004).

Pedagogically, sperm competition provides an engaging strategy for illustrating the nature of science, and can be used to emphasize the predictive nature of hypothesis testing. These predictions range from the simple "if a female mates with more than one male, we expect to see fitness enhanced in those males who can produce more or better sperm" (see Fitzpatrick *et*

al. 2009) to the more complex “kin selection could result in cooperation among closely related sperm, and competition among sperm from rival lineages” (see Fisher and Hoekstra 2010).

Investigating the extent to which sperm competition has shaped human evolution is a field fraught with controversy. Conflicts stem from disagreements over the extent to which humans evolve, the nature of human polygamy (etc.) and the work on human sperm-competition is open to standard criticisms inherent in any studies of living humans (e.g. lack of suitable controls, inability to manipulate mating pairs). Those within the discipline debate whether, and to what limits, sperm competition has influenced modern humans (e.g., Gomendio 1998 versus Baker and Bellis 1995; also see Shackelford *et al.*, 2005). Yet these complexities make this topic excellent material for involving students in timely and relevant discourse about the nature of science.

The course ‘Evolution and Biology of Sex (Biology 1003)’ at the University of Minnesota is a biology course established to teach biology, genetics and evolution to non-science majors. The course was designed to serve those seeking to fulfill a natural-science graduation requirement (see Khodor *et al.*, 2004), while hopefully leading students to an appreciation of the value of biology, personally via topics such as birth control and disease prevention, and socially via topics such as sexual orientation, gender, and sexual violence. The fact that Biology 1003 reaches capacity sooner than any of the other introductory biology courses at our institution is a testament to the appeal of such a course. In its four years of existence, approximately 2500 students have taken “the sex class”.

Sperm competition in the Introductory Biology Laboratory

While making the nature of science and genetics more “sexy” has often just involved strategic use of examples (e.g., dung beetle testes in place of finch beaks, to illustrate selection pressure on a continuous trait; see Simmons and Garcia-Gonzalez, 2008), devising a laboratory class for sperm competition posed a challenge. However, a sperm competition laboratory activity seemed essential because this is a topic that students want to reflect upon, return to throughout the semester, and revisit several semesters after final grades are returned. Students are fascinated by competitive sperm (e.g. Simmons and Garcia-Gonzalez, 2008, Locatello *et al.*, 2006, Evans *et al.*, 2003, Donaghue *et al.*, 1999), cooperative sperm (Fisher and Hoekstra, 2010, Moore *et al.*, 2002), and cryptic female choice (Eberhard, 2004, Olsson *et al.*, 1996), including how sperm competition has shaped human evolution. Students (professed non-scientists in all cases that the authors are aware of) ask for the articles on human male ejaculate manipulation (Baker and Bellis, 1989; 1993), testes size (Dixson, 1987) and mate guarding (Harris, 2004; Meston and Buss, 2007). Given overwhelming student interest and the explicit pedagogical aims of the course, developing a laboratory class that investigated the evolution of humans, via sperm competition, was considered a high priority.

Gallup *et al.* (2003) tested whether the human penis could be adaptive as a tool for sperm displacement, in a similar vein to the sperm-gouging apparatus employed by many arthropods (e.g. Hosken and Stockley, 2004). Specifically, the authors used phallus models (“dildos”) of various sizes and shapes to displace artificial semen pre-inserted in artificial vaginas; volume displaced was compared for dildos with greater diameter and more pronounced features. The results supported the hypothesis that the human penis is morphologically adapted, via the glans and coronal ridge, as a device for sperm competition. This paper presented an ideal model for investigating sperm competition in Biology 1003. The materials (dildos, lubricant, vagina models, mounting platforms for the vaginas) were inexpensive and easy (if embarrassing) to find and purchase, or, in the case of the artificial semen, to make. Data analysis was straightforward, and conclusions could be reached without advanced statistical analysis.

In the spring term of 2011, approximately 350 students participated in a “Sperm Competition Laboratory”, modeled on Gallup *et al.* (2003). The explicit goals of the practical were to gain an understanding of sperm competition itself, and especially to evaluate human evolution in the context of sperm competition. An implicit goal of this and most laboratory exercises in the course is to engage students in the process of science, namely by articulating hypothesis-based predictions and designing appropriate and meaningful experiments. Ideally, students will scrutinize all assumptions, be wary of erroneous but facile connections, and question their peers’ conclusions.

Laboratory exercises

Students were introduced to the concept of sperm competition in general (a familiar theme from the lecture discussions), along with many examples of non-human adaptations to female promiscuity. Then, students were encouraged to hypothesize which aspects of human anatomy, if any, might reflect adaptations to female promiscuity. Next, they were given a specific task to “design an experiment to test whether the human penis is an adaptation for sperm competition” and a box of available resources. These included dildos of various diameters and variation in the extent to which the glans and coronal ridge exceed the diameter of the penile shaft, vaginal lubricant, artificial vaginas, mounting platforms at different angles, ingredients for making artificial semen, and a digital scale.

Students discussed possible predictions, such as a penis with a more pronounced glans and coronal ridge will displace more resident semen than will a penis that merely tapers from the base to the tip — like that of the male chimpanzee. Working in groups of four, they went on to design and conduct their experiments. Students were encouraged to establish controls where necessary, employ repetition, and take careful notes. They graphed their data and interpreted these results in light of their initial predictions. After sharing small-group results with the entire laboratory section (20–24 students), the model paper was presented to the students. For a small homework-grade, each student was responsible for turning in his or her graph and written interpretation, including a written explanation of how penile morphology could be seen in an evolutionary context. Students were encouraged to be critical where appropriate, and were given free reign (albeit constrained by logic and available evidence) to dispute conventional wisdom or the conclusions of the model paper.

In articulating predictions to test in the laboratory, many students unknowingly mirrored Gallup *et al.* (2003) and focused on the configuration of the glans and coronal ridge. Some groups, however, chose to test the effect of penis diameter on semen displaced; some groups focused on vaginal angle during penile insertion; a few tested depth of thrust or time spent thrusting. Sample results are presented in Figure 1.

Assessment

Two multiple-choice questions on the final exam addressed sperm competition. In one, students were asked which environmental conditions favored sperm competition, with “where females mate with several males” being the preferred option. Students performed well on this item (~88% correct), similar to how students have performed in the past. Another question asked for an interpretation of a figure from Baker and Bellis (1993), in which ejaculate size varies with time a mating pair has been apart; the best available answer is “males are capable of manipulating ejaculate size in accordance with sperm competition theory.” Students performed much better on this item (~75% correct) than did students in the previous two semesters (61% and 55%). However, it is difficult to judge the impact of one practical on one such metric. Thus, we turned to follow-up data on student perceptions.

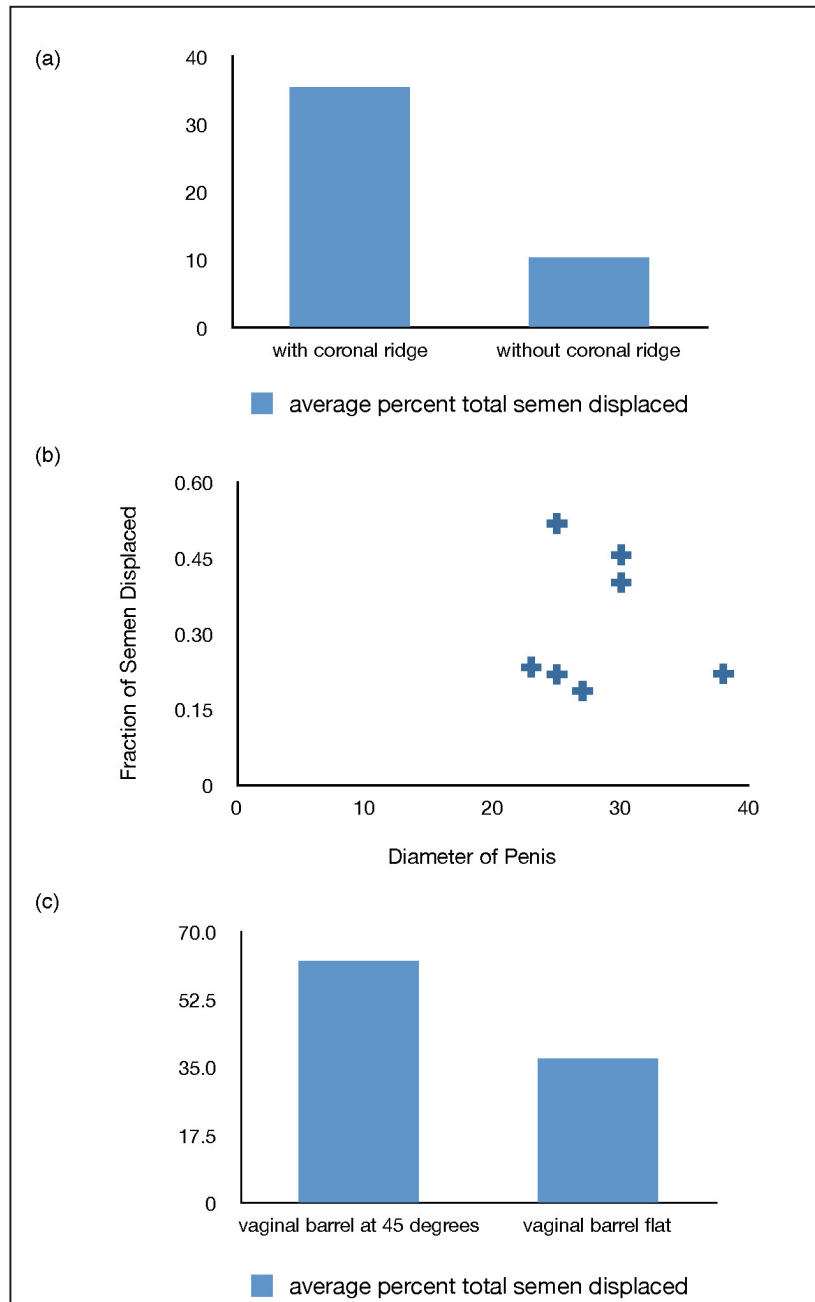


Figure 1 Sample student results. Students tested various predictions concerning the role of (a) penile overhang; (b) penis diameter; and (c) vaginal angle during insertion

Three months after the course concluded, students were sent an electronic invitation to complete an online survey about their laboratory experience in the course. For each exercise, students were asked if they remembered a given laboratory class and if the exercise achieved its stated goals. Students responded to each item on a four-point Likert scale, from 1 = strongly disagree to 4 = strongly agree. For each laboratory, students were invited to comment on any aspect of the experience. Ninety-four students, or approximately 30% of the students from the spring semester, participated in a five-day survey window. Summary results are presented in Figure 2.

Students remembered the sperm competition session more than any of the other laboratory class, and students felt it helped them accomplish the stated goals (scoring 3.65 out of 4 on the item “this lab helped me understand sperm competition,” and scoring 3.49 out of 4 on the

item “this lab helped me understand human evolution”). In addition, over 90% of respondents agreed (or agreed strongly) with the statement “this lab seemed relevant to life outside of biology classes.” The sperm competition class did occur later in the semester (session 10 of a 13-week series), however classes taught after did not, in general, fare better in recall or student perceptions (Figure 2); therefore, it seems any bias due to scheduling must be minimal.

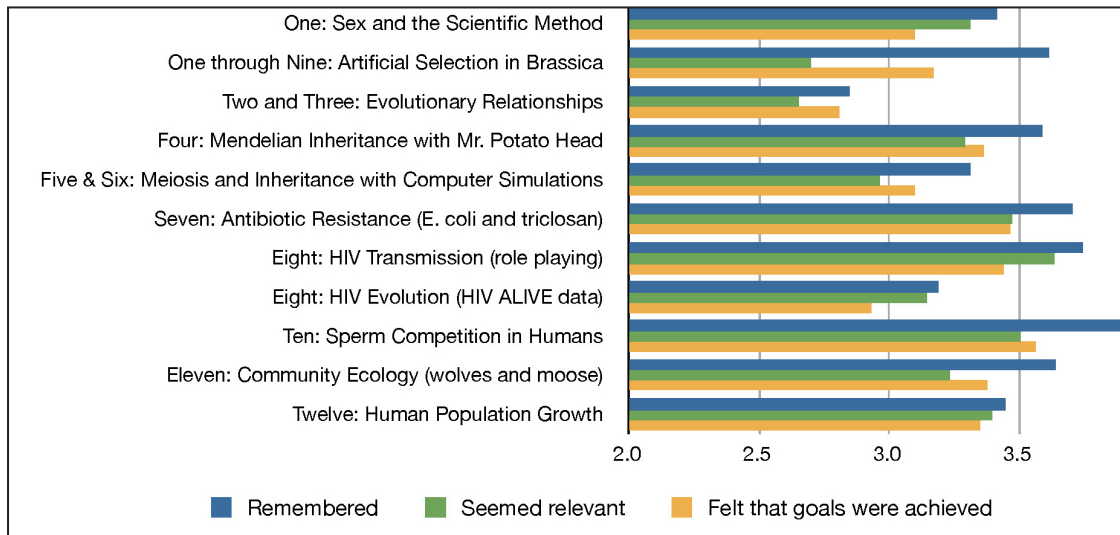


Figure 2 Student perceptions of the laboratory exercises. The sperm competition laboratory session fared well in student memory, being the most memorable and among the most relevant. Students perceived that the laboratory activity succeeding in achieving its stated goals (i.e., “gaining an understanding of sperm competition” and “evaluating human evolution in the context of sperm competition”), with a combined average of 3.57 out of 4.00, with 4 = strongly agree)

Several additional lines of evidence suggest that students viewed the laboratory experience positively. Many took pictures, “tweeted” about the laboratory exercise, or posted laboratory-related updates on Facebook. Several requested more information about sperm competition in humans. One student wrote a poem about sperm competition, and another posted a topical music video on youtube (<http://www.youtube.com/watch?v=AxmUWJM1Be8>). The sperm competition practical also elicited far more open-ended comments (22 of 94 responses; a few second-place practicals elicited 12 comments) than did any of the other laboratories. The word “awkward” was used in four of these comments, but not necessarily in a negative context. On their open-ended comments, they effused:

“All I can say is: BY GOD KEEP THIS LAB.”

“It was fun and educational, I would recommend more of these type of labs.”

“This lab was so much fun and I remember being extremely embarrassed (I was in control of the penis model)”

“In my opinion, this was the most hands-on lab that we did during the semester. This lab was probably my favorite simply because of the hands-on exercise and simplicity. Also, there was a lot of information to be learned and taken away from this lab.”

“Awkward... but a great story that I share whenever telling friends about the class!”

“This lab was so fun! It helped me understand human evolution really well.”

“I must say this was the best lab. EVER.”

“Best lab out of all of them.”

Negative comments represented the minority of the open-ended statements (four of 22), and included constructive criticism:

"While this lab was funny, it was so loosely structured and unclear that it didn't actually make any sense. No one's hypothesis was clear, the data didn't really garner any interesting results. I think it was more interesting for shock value than information. Potentially informative if it was more structured."

"It would have been nice if the students took it more seriously -- again not a coursework problem but perhaps a facilitator could have aided in this."

And at least one respondent found the subject matter too awkward:

"Although it was relevant, I remember this lab because it was my least favorite. It was sticky, gross and uncomfortable. There has to be a better way to communicate this lab's lesson."

The teaching assistants appeared to enjoy facilitating this laboratory session, contributing helpful comments:

"Although I had several comments about "awkwardness" they did a good job of making a hypothesis, thinking of ways to control other variables, and interpreting the data. They were definitely more enthusiastic about the scientific method this semester than last semester."

"They will not forget the concept of sperm competition, ever. Several of them commented that no other lab we did after that week would be able to compare to how fun that one was."

"If nothing else, my students have definitely learned the importance of lubricant."

Discussion

Several studies have suggested that students learn more when they are engaged with the material (e.g. Glynn *et al.*, 2007), and this work suggests that both sperm competition and human evolution are engaging topics for non-science majors. In addition, several features of this laboratory exercise make it specifically amenable to evolution education. Hillis (2007) suggests ways to improve evolution coverage in biology textbooks (and presumably evolution education overall). Four of these themes applied to the sperm competition exercise:

Demonstrate that evolutionary research is current and ongoing

The evolution of sperm competition in humans continues to be a dynamic discipline for scientific investigation including the works of primatologists (Martin, 2007; Harcourt *et al.* 1995), physiologists (Anderson and Dixson, 2002), and psychologists (Goetz *et al.*, 2005; Buss, 2006). As much of this work dates from the past two decades, students should be convinced of its timely significance. Instructors can facilitate discussion of further avenues of inquiry, and research to anticipate in the coming years.

Use fresh examples

A quick glance at any introductory biology textbook will illustrate that the evolution of sex (especially in humans) is barely mentioned, if at all. Few would claim that sex has not been critical to shaping the evolution of non-human taxa, thus it strains credulity to assume human sexual life-histories are unimportant. However, sperm competition only matters in promiscuous species, and the existence or extent of human female polyandry is a controversial topic for many students and educators. In addition, human adaptations are just, if not more, likely to fall victim to "just-so" stories, whereby evolutionary explanations are invoked without robust empirical support. With appropriate guidance, these features only make this topic potentially more engaging for students. While students may disengage the moment they hear repetitious

information about oft-cited Galápagos finches or peppered moths, semen displacement is likely to get their attention. As one student noted, “this was by far the most interesting and thought-provoking lab”.

Show how evolution is relevant to human lives

Students perceived as most relevant the HIV, sperm competition, and antibiotic resistance practicals. These were also the three laboratories they remembered and three that generated many positive comments. Other authors confirm the value of antibiotic resistance (Paz-y-Mino and Espinosa, 2009) and HIV evolution (Hillis, 2007) in teaching evolution at the introductory level. Our data suggest that, rather than shy away from human evolution (or restrict it to an overview of fossil remains), instructors will be rewarded by challenging students with meaningful dialogue about how evolution matters to contemporary humans (also see Nelson, 2008).

Use examples of evolutionary biology from popular media

Popular media (magazines such as Cosmopolitan and Maxim, blogs, and science digests such as ‘ScienceDaily’: www.sciencedaily.com) thrive on stories about the science of sex. Of particular relevance, Gallup *et al.*’s (2003) paper spawned several blog posts about the legitimacy of the author’s premise, work, and conclusions (e.g. Davis, 2011; Bering, 2009), a dialogue that is likely to engage students as well, and could lead to an appreciation of the tentative, incremental, and self-correcting nature of scientific research. In addition, debate over this topic in general provides an excellent vantage point for discussing the social nature of scientific research, often cited as a critical dimension for engaging nonscientists (Chamany *et al.*, 2008; Roth and Lee, 2003).

With enhanced engagement come probing questions from perceptive students. Addressing unexpected questions provides an opportunity for illustrating discovery at the forefront of scientific research, but laboratory instructors may find some questions arise more often than others. We identify some of the most common or provocative here:

What about self-semen displacement?

That is, if the configuration of the human penis evolved to displace rival male semen, what’s to prevent a man’s penis from displacing his own semen? In response, one could mention physiological and behavioral changes that occur during the post-ejaculatory period and that may function to minimize self-semen displacement (e.g. penis hypersensitivity, shallower and less vigorous thrusting, loss of the erection, the refractory period; see Gallup *et al.*, 2004). This question, like so many questions students may have, provides an opportunity for leading students to the literature, or guiding them in a discussion of testable hypotheses.

Is double-mating really a selective force in humans?

That is, what’s the probability of finding semen from two or more males in a woman’s reproductive tract? The existence and extent of female polyandry is one of the most contentious aspects of this work, and is a key assumption underlying any male adaptations for sperm competition. Gallup *et al.* (2006) have shown that insemination by multiple males is much higher than many people imagine (e.g. over one out of every eight coeds admit to having had sex with two or more males within a 24 hour period).

What is the actual incidence of non-paternity in humans?

The best available evidence based on a meta-analysis of the human non-paternity literature is that the incidence of non-paternity varies between about 15 and 54% (Anderson, 2006). When you take into account variation in paternal confidence, men with high paternal confidence have a 1 in 50 chance of being cuckolded (2%), while those with low paternity confidence (i.e.,

who have reason to question their paternity) are 15-times more likely to be cuckolded (30%). Yet a range of double-mating percentages are documented in the literature, and potential explanations for these disparities provide additional fodder for discussion.

Does circumcision matter?

Some students may also raise questions about circumcision and the effect that may have on semen displacement. Gallup and Burch (2004) argue that in fact it may enhance the displacement properties of the human penis. In this and other cases, interested students could be referred to the appropriate sources, or encouraged to do some literature searches on their own.

Does the female matter?

A few students echoed the concerns of a blogger, who stated “In all of this work and study, the woman is completely neutral, just a bystander in the process” (Davis, 2011). Other work can be cited to suggest that human females are not simply bystanders with respect to sperm competition (Eberhard, 2009, 1998; Gangestad *et al.*, 2010; Greiling and Buss, 2000, Thornhill *et al.*, 1995), and male genital anatomy is, at best, a twig in a tree of adaptations to promote genetic representation in the next generation.

A possible discussion topic after the laboratory session is to examine the differences students may find in outcome due to variation in technique, thrusting, vaginal angle, and lubrication, and discuss how these issues may have been addressed by our evolutionary history. In other words, the laboratory project not only illustrates semen displacement, but because of variation in technique it also serves as a compelling illustration of how evolution might have operated to solve the problems students encounter in trying to approximate effective semen displacement. For example, when a woman is lying on her back, her vagina is actually positioned at a 45-degree angle.

Conclusion

As suggested by student comments, establishing clear roles and expectations will be key to ensuring the success of this laboratory. Instructors will need to set a tone that enables free inquiry without sacrificing decorum or mutual respect. As setting the appropriate tone and establishing trust take time, this laboratory exercise is discouraged early in a laboratory sequence. By offering this activity later in a laboratory curriculum, instructors should be able to identify those students most at risk of discomfort and potential alienation, and therefore most in need of additional assistance. However, student input and performance, along with many recommended features of the described activities, lead us to conclude that the sperm competition laboratory is an excellent tool for engaging students in the science of sex and human evolution.

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