INTRODUCTION

The processes of mitosis and meiosis can be difficult for students to visualize. This is true at an introductory level; it is just as true at more advanced levels, where students must understand precisely the nature of a chromosome and how cell division affects ploidy, recombination, and trait transmission. One way to reduce abstraction is by the use of physical models, especially ones the students can manipulate themselves (1). Examples of chromosome models for meiosis include pipe cleaners (2), humans (3), and paper. Some models, on the other hand, focus primarily on the random selection of chromosomes from meiosis and the transmission pattern that results. One example involves the use of Reebops, marshmallow creatures (4).

This paper presents a modification of the Reebops procedure for college laboratories or flipped classrooms that allows students to seamlessly transition from a complex modeling of chromosomes during mitosis, meiosis, and specifically oogenesis into a characterization of complex transmission patterns in the offspring. At every step, students kinesthetically manipulate models. This aids student understanding and allows them to enjoy what is otherwise perceived as rather dry material.

PROCEDURE

This module (Appendix 1; answer key in Appendix 2) is designed for students in a Genetics class who have been introduced to the movement of chromosomes through mitosis and meiosis but who, so far, have only a basic knowledge of Mendelian genetics (see Appendix 3 for more information on terms and ideas to which students should already be introduced, as well as materials required).

In short, Reebops are marshmallow creatures (Fig. 1) with phenotypes determined by genes on chromosomes. In this model, unlike in other adaptations of Reebops, the chromosomes coming from the female are represented in replicated form. In other words, there are four strips of paper with the B gene, two of which are double-stranded DNA molecules from one chromosome (B), while the other two form the homolog (b). Each diploid Reebop cell has 14 chromosomes.

Students follow through the stages of mitosis and meiosis as they affect the female chromosomes, taking pictures as they go with (nigh ubiquitous) cell phones. As they proceed, they answer questions about ploidy and oogenesis. Questions are designed to be answered simply but require an understanding of exactly what chromosomes are and what is happening to genetic information. At the end of “meiosis,” students graph the number of double-stranded DNA molecules and chromosomes through time. This allows them to put together what they have learned; it also allows the
instructor to see misunderstandings at a glance and correct them. Some common errors involve not understanding when one chromosome becomes two (anaphase of mitosis and anaphase II), or not understanding that each chromatid is a double-stranded DNA molecule. These misperceptions are difficult for many students to recognize until they are forced to confront them. Students also observe the (haploid) set of alleles remaining.

Students randomly select chromosomes from the male Reebop, then use a genotype-phenotype map to make their own Reebop. At this point, the students are told exactly what combinations of alleles result in each phenotype. They then consider how this might happen, which introduces them to more complex modes of inheritance. Thus they encounter simple dominance, sex-linked traits, incomplete dominance, multiple alleles, and polygenic traits. They also are exposed to the idea that offspring ratios are expectations, not always met, and that genes on the same chromosome may be linked.

This module requires approximately two hours, following any required explanation. It can be done in two units, with a breaking point just before or after Reebop construction.

CONCLUSION

I assessed the success of this module in two ways. I surveyed the students to determine their attitudes toward the exercise (Fig. 2, Appendix 4). More than 97% found it useful, while 95% thought it helped them understand the material. More than 85% felt more engaged in the class afterwards, with the same percentage considering it an effective use of lab time. Somewhat fewer students (~75%) felt that the assignment helped them memorize terms or accomplish something that could not have been learned easily through lecture.

I also assessed learning directly through a pre- and post-lab quiz (Fig. 3). The students were randomly divided into two equal-sized groups to take extra-credit quizzes on topics covered by the exercise. One group took quiz version A prior to lab and quiz version B after lab. (These quizzes had no questions in common.) The other group took quiz version B prior to lab and quiz version A afterwards. The average quiz score increased from 53.4% to 69.7%, representing a significant increase in performance following the exercise (by two-factor ANOVA, \( p < 0.0003 \)).

In a way, the Reebop construction is tangential to this lab and could be removed, with minor alterations to the text. However, it reinforces the tactile nature of the lab in general, which takes concepts that are typically abstract and makes them concrete. Students observed and took note of the differences between their Reebops and those of other students. Many students mentioned specifically that they enjoyed making Reebops, even though it took only a small proportion of the time devoted to the exercise.

FIGURE 2. Combined survey responses from both classes \((n = 40–41); one student did not answer the memorization question\). The proportion strongly agreeing or agreeing (light and dark green) is marked above each bar.
The differences between mitosis, meiosis I, and meiosis II can be difficult to internalize even for upper division students. It is also easy for students to fail to make the connection that more complicated transmission patterns typically represent the relationship between alleles and phenotype rather than differences in allele transmission per se. This connection is emphasized by the holistic nature of this exercise.

FIGURE 3. Average quiz scores before (black) and after (grey) lab exercise. Twenty students took quiz A first and B after the exercise, 20 students did the reverse, for a total of 40 pre- and post-exercise quizzes. The maximum score was 8. Quiz questions are available on request.

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