Sex-specific Differences in Meiosis: Real-world applications

Benedict J. Kolber[1]*, Mary Konsolaki[2]*, Michael P. Verzi[2], Cynthia R. Wagner[3], Joseph R. McCormick[1] and Karen Schindler[2]*†

[1] Department of Biological Sciences, Duquesne University, Pittsburgh, PA

[2] Department of Genetics, Rutgers University, New Brunswick, NJ

[3] Department of Biological Sciences, University of Maryland, Baltimore County, College Park, MD

* Authors contributed equally

Abstract

In traditional classrooms, students are typically presented with facts that they are asked to memorize and recall during an exam. The rapid explosion of available scientific facts in recent years has made this model of teaching impractical. In the current informational landscape, students would be better equipped by being able to evaluate and critically analyze scientific data. As an alternative education approach, we have developed a student-driven lesson plan that utilizes active-learning techniques. Our lesson plan focuses on teaching the differences in meiosis between human sexes. Students come to class having read background material. During class time, they engage in activities that challenge both their basic understanding of concepts as well as how to apply these concepts to real-world situations. The instructor facilitates and clarifies misunderstandings. The Lesson was tested at three institutions in different levels of courses and class sizes, which provided learning assessment data that are presented here. Our data show that the overall learning success of this specific content (meiosis) was similar in a traditionally taught classroom versus our active learning-based lesson. However, based on our own experiences, we observed that student participation in this active-learning lesson was noticeably higher than in any of our traditionally taught classes. Our active-learning lesson highlights the benefits of using active learning techniques in achieving not only learning of content but also increasing student ability to apply the learned material to real-life situations. Although we have applied these principles in Genetics and General Biology courses, they are applicable to a wide range of topics and subjects.

Learning Goal(s)

Students will understand the fundamental timing differences that exist between human male and female meiosis. After this lesson, students will know why rates of non-disjunction in meiosis occur primarily in older women. Finally, students will appreciate the importance of meiosis in the process of reproduction and fertility issues that occur in older females.

Learning Objective(s)

After completion of the lesson students will be able to:

1. Describe the differences between female and male meiosis.
2. Interpret graphical data to make decisions relevant to medical practices.
3. Develop a hypothesis that explains the difference in incidence of aneuploidy in gametes between males and females.

Citation: Kolber, B.J., Konsolaki, M., Verzi, M.P., Wagner, C.R., McCormick, J.R. and Schindler, K. 2014. Sex-specific Differences in Meiosis: Real-world applications. *CourseSource.* 00:xxx. doi:00.0000/journal.cs.000000

Editor: Kathy Miller, Washington University, St. Louis

Received: 4/03/2014; **Accepted:** 7/07/2014; **Published:** 12/01/2014

Copyright: © 2014 Kolber, Konsolaki, Verzi, Wagner, McCormick and Schindler. This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License, which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original author and source are credited.

Conflict of Interest and Funding Statement: The authors have no financial conflict of interest to disclose. Initial design of lesson plan occurred at the National Academies Summer Institute on Undergraduate Education (Harvard University, 2012) but no direct funding was received for the creation or implementation of the lesson plan. Lesson plan was initiated in courses by the original designers of the lesson plan.

Materials and Supplemental Materials: Table 1. Sex-Specific Differences-Teaching Timeline, Figure 1. Sex-Specific Differences-Scores on pre and posttest clicker questions, Figure 2. Sex-Specific Differences-Essay grades, Supplemental File S1. Sex-Specific Differences-Case Study, Supplemental File S2. Sex-Specific Differences-Strip Sequence Description, Supplemental File S3. Sex-Specific Differences-Strip Sequence Template, Supplemental File S4. Sex-Specific Differences-Video file for Case Study, Supplemental File S5. Sex-Specific Differences-PowerPoint Presentation, Supplemental File S6. Sex-Specific Differences-Prezi Presentation and Supplemental File S7. Sex-Specific Differences-Recommended supplemental reading references

[*]**Correspondence to:** 145 Bevier Rd, Piscataway, NJ, 08854 Phone: 732-445-2563

INTRODUCTION

Traditional content delivery in instructor-led classrooms is outpaced by the ever-increasing amount of available information. Traditional teaching in lecture halls involves students dutifully taking notes while the instructor delivers a well-thought out lecture from the podium, but there will never be enough lecture time to cover everything. In addition, the ubiquitous availability of information access is challenging the traditional emphasis on "memorization" as part of an educational plan. As an alternative to memorization, educators are emphasizing the critical analysis and application of new knowledge to real-life problems. In response to these trends and in an effort to evaluate Active Learning techniques (http://www.academiessummerinstitute.org) in our classrooms, we developed a lesson unit that incorporates student driven teaching and learning [a "flipped classroom" approach (1)] in combination with interactive and diverse learning exercises.

Lesson content

The lesson that we present here is based on teaching a basic concept in any Biology or Introductory Genetics course. Our specific example demonstrates an interactive way to teach the process of meiotic cell division and the generation of germ cells in diploid organisms such as humans. This concept is crucial for understanding the differences in germ cell formation between males and females in dimorphic species. In addition to a simple understanding of a basic biological process, meiosis has real life significance in professional fields of biology. These include fields that are currently undergoing major technological breakthroughs, such as human reproduction and technologies that relate to fertility. Moreover, this particular area of biology invites discussion on the ethics of facilitating human reproduction (2) which include discussing the best way to distribute, fund and provide access to modern reproductive technologies for family-building needs and fertility preservation.

Intended student population

The intended student population for our active-learning lesson is first- or second-year undergraduate students. At the discretion of the instructor, the material can be adjusted for use either for students intending to major in a biological science or for non-science majors who are fulfilling a science requirement. In both cases, students will be asked to engage actively in the reconstruction of background knowledge and the application of this knowledge to develop higher-level understanding of concepts. The instructor could find basic information on the mechanics of meiotic division in any textbook that focuses on General Biology, Cell Biology, Molecular Biology, or Genetics. Such material can be assigned as pre-class reading and, depending on the level of the intended audience, it can be supplemented with more recent review articles from current literature (3). This material can also be adapted for upper level courses by including primary literature that supports the findings described in this lesson. A list of primary literature that could be used for this purpose can be found in the supplemental materials.

Learning time

The time that should be allotted for this active-learning lesson would cover about half of one traditional class period (~25 min). Students should supplement the classroom time with time spent covering the pre-class material. Depending on the level of the course where this lesson is being implemented, students may be asked to carry out literature searches, either before the lesson or after. This exercise can help students explore the current status of research on meiosis, technologies that relate to fertility issues, or the ethics of reproductive technologies.

Prerequisite student knowledge

Prerequisite knowledge is divided into two components. The first component includes information that was covered in previous lectures or in-class lessons. This material includes general details on meiosis and, to a lesser extent, sexual reproduction. Students should be familiar with chromosome separation as in occurs in meiosis I vs. meiosis II. The second component involves the "pre-class preparation" described below.

SCIENTIFIC TEACHING THEMES

<u>Active learning</u>

- *Activities outside of class: Textbook and primary literature reading when Lesson is used in a higher-level course.*
- *Activities in class: Strip sequence, clicker question from case study video and data graph, 1-minute essay.*

<u>Assessment</u>

- *Pre-class: The strip sequence activity is graded. Grading of this activity enables assessment of learning of the pre-reading material. The strips are returned to the students before the instructor's discussion of meiosis.*
- *Post-class: Clicker question and 1-minute essay.*

<u>Inclusive teaching</u>

- The class activities address different learning styles through the use of audio/visual material, tactile activities (paper strip), and reading at home.
- Teaching material also addresses how modern reproductive technologies are applied to contemporary family needs and diversity of sexual orientation.
- Working groups that are formed randomly ensure inclusion of students with different background knowledge and abilities.

LESSON PLAN

Pre-class preparation

Students: Before this class, the students should already have working knowledge of basic concepts of mitosis and meiosis from other course lessons. For this lesson, students are assigned pre-class reading material that covers the basics of mammalian meiosis and gametogenesis. This material should include the differences in the timing of gamete production in male and female humans. We find that the Molecular Biology of the Cell (Garland Science, 2002, 4th Edition, Chapter 20) and Biology: How Life Works (WH Freeman, 2013, 1st Edition, Chapter 42) textbooks each have a chapter devoted to this topic. Ultimately the reading material choice is at the discretion of the instructor and should be tailored to the background level of the students. The goal of the reading assignment is to have the students begin class with the same level of background knowledge so that they can equally participate in the learning activities.

Instructor: The instructor should be familiar with the lesson material and anticipate where questions in the activities may arise. For example, in the "Strip Sequence activity" (described below), we have included two strips that are labeled "symmetric cell division." Students often wonder if this is a mistake and we reassure them there is no mistake. Other students are concerned that there is an odd number of strips. We reassure them that strips do not have to be evenly distributed between male and female. Finally, for the clicker question, the students need to choose the best answer based on the data presented. They may have learned additional information elsewhere, but

TABLE 1: SEX-SPECIFIC DIFFERENCES-TEACHING TIMELINE

ACTIVITY	ESTIMATED TIME	NOTES/SUGGESTIONS
PREPARATION	15-20 MIN	REVIEW SLIDES, PREP STRIP PACKETS
STRIP SEQUENCE	15 MIN	5 MIN TEAM WORK, 10 MIN DISCUSSION
CASE STUDY	5 MIN	INCLUDES VIDEO, DATA ANALYSIS AND CLICKER QUESTION
ESSAY	5 MIN	ALLOWS THINK-PAIR-SHARE AND WRITING TIME

KOLBER, B.J., KONSOLAKI, M., VERZI, M.P., WAGNER, C.R., MCCORMICK, J.R. AND SCHINDLER, K. 2014. SEX-SPECIFIC DIFFERENCES IN MEIOSIS: REAL-WORLD APPLICATIONS. *COURCESOURCE.*

the point of the exercise is to use the data at hand.

The instructor should also prepare the materials for class. These materials include the paper strips for the Strip Sequence activity, setting up the clicker question, and ensuring that the case study video and PowerPoint or Prezi presentation work.

In-class script for instructor

The lesson begins with the Strip Sequence activity. This activity allows students to compare and contrast the steps of male and female gametogenesis by putting strips that each contain a description of one step in temporal order. The activity is introduced and explained after the packets with the strips are handed out. Each packet should contain 11 strips with terms plus two strip headers.

Strips: Each strip describes a step in meiosis that occurs in either human males or females.

Headers: a strip with "Male" and a strip with "Female" so that the meiotic steps can be separated into two columns, based on whether eggs or sperm are being produced.

Working in teams of 3-4, students first sort the terms based whether they occur in males or females, and then place the terms in chronological order underneath the Male or Female header, based on biological context. The students are given ~ 5 minutes to complete the task. The instructor and teaching assistants should circulate the room for assistance and to encourage participation.

If the class size is large and having packets is cumbersome, the instructor could elect to show a slide with the strip terms in scrambled order. The students could use their own notebooks to categorize and re-order the terms.

Once time is complete, the strip sequence answers are presented one at a time, in the correct order (using the animation feature of PowerPoint) so that the instructor can slowly walk the students through the correct answers and provide additional explanation. Before revealing each step, a group of students is called upon to provide their answer and explanation. The class is asked if they agree. If there are disagreements, the students lead a discussion and explain their answer to see if they can come to a consensus. Next, the instructor reveals the correct answer. To ensure that all students understand the correct answering and reasoning, the instructor reiterates why that event is the correct answer and relates it to the pre-class reading. Depending on the level of the class, the amount of lesson time available, and the desire of the instructor, more or less information can be incorporated into the explanation. After all answers are revealed, the answers are repeated to solidify the concepts.

Next, the instructor transitions into the case study. The tasks involved in the case study include a clicker question, think-pair-share activity and a 1-minute essay. This activity is centered around highlighting the consequences of meiotic errors on human reproduction. The instructor explains that a short video will be shown (1.5 min) and that, although the video has some comic relief, it is meant to demonstrate a real life clinical situation. The scenario depicted in the video, involves a discussion in an in vitro fertilization clinic between a doctor and a same-sex male couple. The couple wishes to conceive a child using an egg donor and is looking for advice on the best donor to use. Through the activities, they learn that the incidence of Down Syndrome increases in maternal age. This scenario presents several controversial matters.

First, the video addresses real issues faced by same sex couples that wish to start a family. The instructor can handle the scenario at their discretion. We recommend highlighting the recent repeal of the Federal Defense of Marriage Act (DOMA) without judgment or commentary. This makes this scenario all the more real. It can also be highlighted that those students who will be in clinical practice may have to face this sort of scenario. Second, some cultures and religions do not support creation of life through the in vitro techniques. Generating a discussion to enlighten students of this fact has been successfully implemented in a Rutgers "Implications of the New Genetics" elective course. This discussion began with an online, anonymous poll sent out before class asking students response, Yes, No, or Undecided on the following comment: "If my partner and I were faced with infertility we would elect to conceive by in vitro fertilization." The instructor began an in class discussion of the topic by presenting the responses as a graph. Students then openly commented on their stances and engaged in a discussion that was proctored by the instructor. Finally, there is opportunity for an ethical discussion around movements to avoid the generation of children with Down Syndrome. The topic includes the obvious issues of embryo destruction or abortion. In addition there is the legitimate concern from the Down Syndrome community that, if their population becomes smaller, fewer resources will be available for assistance. Furthermore, there is the fact that Down Syndrome represents a viable and natural human biological variant and that there is nothing "wrong" with having Down Syndrome. Although challenging, an individual with Down Syndrome can live a fulfilling and satisfying life. Therefore, at the discretion of the instructor, these topics could be addressed in a classroom discussion or in reflective writing assignments to highlight the impact that scientific technologies have on everyday life.

The students are instructed that they will be answering several clicker questions based on material from the video. To make sure that the students equally understood and heard the case study, the instructor and/or the assistants can hand out the hard copy of the case study. After the video, the instructor shows the data that compare the incidence of nondisjunction that occurs in female versus male gametes. Students are allowed some time to analyze the data (~2 minutes) and then the instructor proceeds to the clicker question. Students are allowed ~1 minute to complete the clicker question. Subsequently, the class distribution of answers is shown and students engage in a 5-minute discussion of why "C," either male, is the best answer. We note that newer data suggest that paternal ageing could also increase levels of aneuploidy and are associated with an increased risk in passing schizophrenia and autism to offspring. Depending on the level of the class, the amount of lesson time available, and the desire of the instructor one could lead a supplemental discussion of this new information or provide the new data for a take-home reading assignment. This discussion would introduce the class to the fact that scientific information is always evolving and rapidly changing.

The lesson concludes with showing the 1-minute essay assignment slide. Here the students will need to think about all the material they have learned through reading and class discussions and to develop a hypothesis that explains why trisomies increase more frequently with age of female compared to male parents. They are permitted to discuss their ideas briefly with a partner before writing their hypotheses and explanation on a 3 X 5 card that will be submitted to the instructor at the end of class. Discussion of the 1-minute essay hypotheses will occur during the following class.

Preparation is estimated at 15-20 min. Implementation of lesson is estimated at 25 min. Please see Table 1 for a detailed time line for this active learning lesson.

Required materials

1. Reading assignment on mammalian meiosis (determined by instructor).
2. Packets containing strip sequence terms and headers or a presentation slide listing the terms in scrambled order (option to use provided supplemental materials).
3. PowerPoint or Prezi presentation containing slides with strip sequence answers, case study video, graph, and clicker question, and the 1-minute essay question (option to use provided supplemental materials). Clickers and programming are provided by the department/school. In the case that clickers are not feasible, students may hold up cards with their answers or ask for a show of hands.

TEACHING DISCUSSION

Teaching the Meiosis Lesson Plan

The lesson plan was used and evaluated at a three institutions including a medium-size private university (Duquesne University; 7000+ students) and two large state universities (Rutgers University 40,000+ students and University of Maryland Baltimore County (UMBC) 10,000 + students).

At Duquesne University, the lesson plan was evaluated in the fall semester of 2013 in two sections of a General Biology course made up primarily of first-year undergraduate students. Section A had 222 students and section B had 217 students (specific attendance was not taken on lecture day). Additional demographic data were not collected but majors in the course included forensics, chemistry, biochemistry, athletic training, pre-pharmacy, pre-physical therapy, pre-physician assistant, among others. Both sections met on Tuesday and Thursday for 1 hour and 15 minutes. To compare the efficacy of the lesson plan compared to a traditional lecture on the material, section A of the course received a traditional PowerPoint-based lecture and section B received the Lesson described here. Before the lecture, students were asked to read Chapter 42-15 to 42-16 in Biology: How Life Works (WH Freeman, 2013) about the timing differences between gamete production in females versus males and about chromosomal abnormalities caused by non-disjunction.

At Rutgers, the State University of New Jersey, the lesson plan was given in consecutive fall semesters (2012-2013) to Genetics Majors. The class size each year was approximately 63 students, and primarily consisted of undergraduate sophomores. Students worked in teams of 4 during the lesson. The strip sequence was taught once with the paper strips, and once with students recording the order of the male/female-specific meiotic events in their workbooks.

At UMBC, the lesson plan was also used in consecutive fall semesters (2012-2013) in the Molecular and General Genetics course. Most of the students in the class (300 each semester) were sophomore Biology majors. A Team-Based Learning (TBL) format was used throughout the semester and students worked in teams of 4-6. In 2012, students ordered the events of meiosis on a sheet of paper. In 2013, students worked in groups of 5 at a table and used the paper strips.

Attitude Outcomes from the Meiosis Lesson

At all three universities, regardless of the way the meiosis lesson was taught, student reactions were overwhelmingly positive (there was one negative comment about the sexual orientation of the clients in the video case study). During the lesson, students appeared more intellectually engaged than usual (more attentive, less texting, etc.) and there was particular excitement about the "applicability" of the science to a tangible profession (genetic counseling). We observed differences in student behavior between student groups that used the paper strips to order the events versus groups that ordered them in a notebook or on a piece of paper. The physical activity of having to sort and order paper strips with meiotic events created much more energy and excitement than the workbook exercise, and students (in the TBL class) asked more questions and had more comments during the "report-back" discussion about the sex-differences in meiosis and how those differences contributed to fertility differences. However, preparing the paper strips involved more teacher time (a one-time effort if the strips are saved for reuse); some problems arose when 2 groups lost some of their paper strips.

Learning Outcomes from the Meiosis Lesson

At Duquesne University, four clicker-based questions were anonymously given to each of 2 sections of first-year General Biology students as a pre-test, before starting the class (Figure 1).

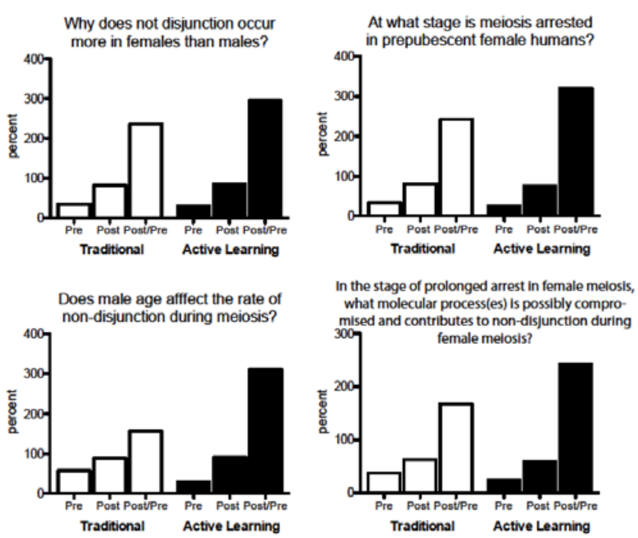

Figure 1. Pre-test and post-test Clicker questions comparing new lesson to traditional lecture. One section of general biology students were given a traditional lecture ("traditional") while another section was given the new active-learning lesson. Four questions were asked before lecture ("pre") and at the beginning of the next class (after the lecture "post"). Similar gains were made by both groups in all four clicker questions shown. Data shown are percent correct ("pre" and "post") or percent increase ("post/pre"; post value/pre value *100) for each question in each type of lecture (i.e. traditional vs active-learning).

These same four clicker-based questions were given again the next time that the class met (after a 5-day break), as a post-test. Finally, scores on a final exam question "Genetic variation. Explain why nondisjunction (leading to conditions such as trisomy 21) is more likely to happen during human female meiosis compared to human male meiosis. In your answer, be sure to describe what trisomy is and what the phenotype is for a human with this genotype. How does the rate of trisomy or nondisjunction change with age in a female compared to a male?" were compared between the two sections. This final exam occurred ~3 weeks after the lesson. Students receiving the new active-learning lesson plan demonstrated a greater percent increase (post-test/pre-test *100) compared to the traditional lecture section. Lower pre-test scores for the active-learning lesson section likely explain these differences on all questions. Comparing the score of a final exam essay question, there was no statistically significant difference between the two sections (Figure 2).

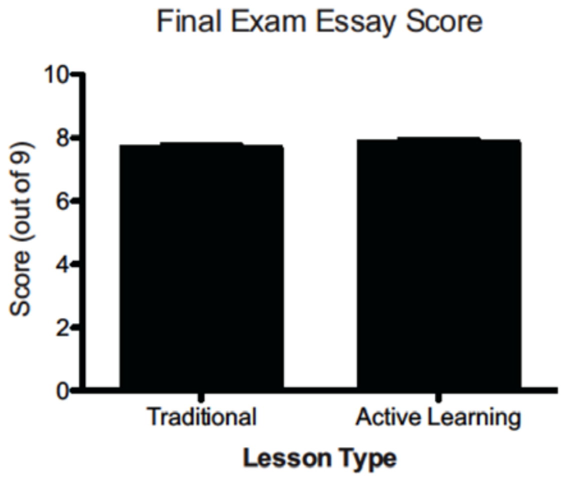

Figure 2: Essay grades on General Biology final exam between traditional lesson section and new active learning lesson section. Students receiving a traditional lecture ("traditional"; n=222) performed similarly to students receiving the new active-learning lesson ("active"; n=217) on a final exam essay question that specifically addressed the material in the lesson. Data shown are the raw scores (out of a maximum of 9) (mean SEM). Unpaired t-test p = 0.34.

Students receiving the traditional lecture had a mean score of 7.69 +/- 0.12 (n=222; max score possible=9) and the section of students receiving the new lesson plan had a mean score of 7.86 +/- 0.13 (n=217). These data show that students receiving this new active-learning lesson plan performed equivalently to students receiving the same material in a more standard passive learning scenario and demonstrate the feasibility of this lesson plan for first year undergraduate students in an introductory biology course. We note that the pre/post test and final exam question reflects a lower level of Bloom's style questioning (Identify, Explain). One may see more evidence of higher-level learning questions focused on analysis and application of concepts.

At Rutgers University, students were asked anonymously whether they strongly agreed, agreed, agreed somewhat, neutral disagreed somewhat, disagreed, or disagreed strongly with the statement "I can hypothesize why the differences in male and female meiosis contributes to sex-differences in fertility decline with aging." 42.2% strongly agreed, 36.4% agreed, 18.2% agreed somewhat, and 3% disagreed somewhat (33 respondents). At UMBC, students reported before the lesson that this was new information and when later tested on this material, 70% of the students correctly ordered the events of human female meiosis on an exam. While such observations do not immediately suggest that this lesson plan is advantageous to learning, the fact that this lesson plan was stimulating to teach and seemed to keep the students more engaged in the lecture makes it a feasible and attractive alternative to traditional lecture in a genetics course.

Regardless of a student's major, all students can relate to real-life data and benefit from learning the processes of data analysis and interpretation. This lesson plan provides such an opportunity in a low-pressure, engaging, and active manner. When compared to a traditional lecture-only lesson on the same material, this new lesson provided equivalent learning gains and the additional opportunity to practice team problem solving and develop communication skills. Future analysis of this and other active-learning lesson plans will necessitate both short and long-term studies that directly compare active-learning to passive-learning strategies.

ACKNOWLEDGMENTS

This lesson plan was developed as a project while the authors attended The National Academies Summer Institute on Undergraduate Education (Harvard University, 2012). The authors are grateful for feedback from Institute leaders and other participants during the development and implementation of the lesson plan. They acknowledge Dr. Philip Farabaugh (UMBC) for contributing to the development of the active-learning lesson, Ms. Amanda Gentilello (Rutgers University) for contributing the primary image, and Dr. Peter Mirabito (University of Kentucky) and Dr. Mary Ellen Wiltrout (Massachusetts Institute of Technology) for facilitating the project development.

SUPPLEMENTAL MATERIALS

- Table 1. Sex-Specific Differences-Teaching Timeline
- Figure 1. Sex-Specific Differences-Scores on pre and posttest clicker questions
- Figure 2. Sex-Specific Differences-Essay grades
- Supplemental File S1. Sex-Specific Differences-Case Study
- Supplemental File S2. Sex-Specific Differences-Strip Sequence Description
- Supplemental File S3. Sex-Specific Differences-Strip Sequence Template
- Supplemental File S4. Sex-Specific Differences-Video file for Case Study
- Supplemental File S5. Sex-Specific Differences-PowerPoint Presentation
- Supplemental File S6. Sex-Specific Differences-Prezi Presentation
- Supplemental File S7. Sex-Specific Differences-Recommended supplemental reading references

REFERENCES

1. **Mazur, E.** 2009. Farewell, lecture? Science. 323:50-51.
2. **Gilbert, S.** 2005. Bioethics and the New Embryology: Springboards for Debate. Sinauer Associates, Sunderland, MA.
3. **Hunt, P., and T. Hassold.** 2010. Female Meiosis: Coming unglued with age. Curr Biol. 20:699-702.