Using Online Lectures to Make Time for Active Learning

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ABSTRACT To make time in class for group activities devoted to critical thinking, we integrated a series of short online lectures into the homework assignments of a large, introductory biology course at a research university. The majority of students viewed the online lectures before coming to class and reported that the online lectures helped them to complete the in-class activity and did not increase the amount of time they devoted to the course. In addition, students who viewed the online lecture performed better on clicker questions designed to test lower-order cognitive skills. The in-class activities then gave the students practice analyzing the information in groups and provided the instructor with feedback about the students' understanding of the material. On the basis of the results of this study, we support creating hybrid course models that allow students to learn the fundamental information outside of class time, thereby creating time during the class period to be dedicated toward the conceptual understanding of the material.

THE lecture hall is no longer the primary portal for the dissemination of information. Instead, the college classroom must embrace a new role as a place where students can work with instructors and peers to apply and evaluate the wealth of information that is available (Handelsman *et al.* 2004, 2007; Ebert-May and Hodder 2008). Students actively engaged in constructing their own learning demonstrate increased learning gains and enhanced retention of course material when compared to students who listen to traditional lectures (Udovic *et al.* 2002; Knight and Wood 2005; Deslauriers *et al.* 2011). Engagement in active-learning exercises like small group learning requires students to communicate their thought processes. Instructors can then gauge whether the course learning objectives are being achieved and can identify and address student misconceptions (Klymkowsky *et al.* 2003; Allen and Tanner 2005; Phillips *et al.* 2008). Implementation of active learning in the science classroom recognizes the value of diversity and increases student retention (Felder 1993; Buncick *et al.* 2001). Given these benefits, national agencies have promoted the inclusion of active learning in undergraduate science education (National Research Council 2000, 2003; Aaas 2011), which raises questions about how to implement active learning while maintaining sufficient coverage of the fundamental information.

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Instructors have been experimenting with new delivery methods, moving away from the traditional in-class lecture and out-of-class problem set model. For example, many instructors are now incorporating online learning components, which have been shown to improve both student attitudes and academic performance (Grabe and Christopherson 2008; McFarlin 2008; Vatovec and Balser 2009). Other models, like team-based learning, flip the standard paradigm and instead require students to read information outside of class to prepare for in-class activities (Foertsch *et al.* 2002). On the basis of these ideas in an attempt to address the content–process tension, we created a hybrid course model in which students viewed an online lecture before class and then participated in group, problem-solving exercises during the in-class time.

The hybrid model was implemented in the first semester of a large, introductory biology course that focused on ecology, evolution, and genetics. For each of the 10 class periods, we produced online lectures and designed in-class activities that targeted the session's learning objectives. Many of the topics, especially those relating to genetics, are notoriously difficult for students to understand (Marbach-Ad and Stavy 2000). By implementing the active-learning exercises, we accomplished two important objectives. First, the instructors were able to clarify student misconceptions and assess what concepts students struggled to understand, and second, the students engaged in challenging problems designed to help the students develop higher-order cognitive skills.

To understand the impact on student learning and their perceived value of the activities, we asked the following questions about the hybrid course model:

1. Did students view the online lectures before participating in the in-class activities?
2. Did viewing the online lectures help students to achieve the session learning objectives?
3. Did students value online lectures as a learning tool?
4. Did the addition of the online lectures increase the amount of time that students spent on the course?

To answer the questions, we used a mixed-method approach that included student performance on clicker questions, surveys, assignments, and other metrics, the results of which indicated that the hybrid course model effectively created time for active learning in the classroom.

Materials and Methods

Class demographics

We implemented this project in the first-semester lecture course of a four-semester undergraduate biology program, Biology Core Curriculum at the University of Wisconsin (Madison, WI) (http://www.biocore.wisc.edu) (Batzli 2005). Through a competitive application process, students are selected to participate in this program and are informed that the curriculum will require them to learn to work productively in groups and to develop critical thinking skills. The three-credit ecology, evolution, and genetics course enrolls ~130 students each fall and is the foundation for subsequent biology courses. The course meets three times per week for 50 min in a large, stadium-style lecture hall; most instructors delivered a typical instructor-centered lecture with out-of-class problem sets. For 10 of 42 lecture periods equally dispersed throughout the semester, we implemented the new teaching intervention that included online lectures to be viewed outside of class time, in combination with in-class group problem-solving activities. The graduate teaching assistants reviewed the information presented in lecture during the weekly 16 student discussion sections. Summative assessments included two midsemester exams and one final exam composed of short-answer essay questions. The instructors designed the examination questions to test students' understanding of the content from the out-of-class lectures and their critical thinking skills based on those developed during participation in the group activities. The students in this course are sophomore honor students majoring in the biological sciences and frequently continue on to complete postgraduate degrees.

Implementation of the hybrid model

The online lectures were developed by the instructors to provide students with the basic knowledge that was needed to participate in the in-class activity. To produce the online lectures, instructors created a PowerPoint presentation and then recorded the associated sound file (*.wav type). In some cases, the sound file was edited using WavePad 3.05. The sound file was converted into an audio file (*.mp3 type) in iTunes and was combined with the PowerPoint presentation). The final presentations were posted on the course website and introduced to students as a required resource to be viewed prior to the class period when the active learning event occurred. The genetics topics included mitosis, meiosis, recombination, quantitative genetics, and probability. The online lectures and their associated learning objectives can be accessed from the Scientific Teaching Digital Library at http://scientificteaching.wisc.edu/library/units/003/.

To evaluate student use of the online lectures, we asked students at the start of each class period whether they viewed the online lecture before class and whether they planned to view the online lecture before the examination. To assess understanding related to the learning objectives based on the online lectures, students answered a series of questions using an electronic audience-response system, or "clickers." The cognitive level of the clicker questions was ranked using the Blooming Biology Tool (Crowe *et al.* 2008). The clicker questions, the designated cognitive level, and associated learning objectives can be found in Supporting Information, Figure S1. For each of the clicker questions, we compared the average number of students choosing the correct answer of those who viewed the online lecture to those who did not and we looked at whether this difference was statistically significant (P-value <0.05) by using the Mann–Whitney test on the Vassar Stats Website (http://vassarstats.net). When students performed poorly on the clicker questions, we encouraged peer discussion and if necessary provided additional instruction (Levesque 2011).

After the assessment with the clicker questions, students spent the balance of the 50-min class period participating in group activities. The faculty instructors and teaching fellows (Miller *et al.* 2008) designed these activities to extend the students' conceptual understanding of the information presented in the online lecture and to help the students develop critical thinking skills. Many of the activities involved drawing since this is one of the most effective ways to elicit student misconceptions (Dikmenli 2010). The worksheet associated with the cell division topic is included in Figure S2 and other genetics-themed worksheets can be access from the Scientific Teaching Digital library at http://scientificteaching.wisc.edu/library/units/003/. Four students worked together in each assigned group, and the faculty instructor, the teaching fellow, and teaching assistants circulated around the classroom to guide the students as they processed the material. An integral part

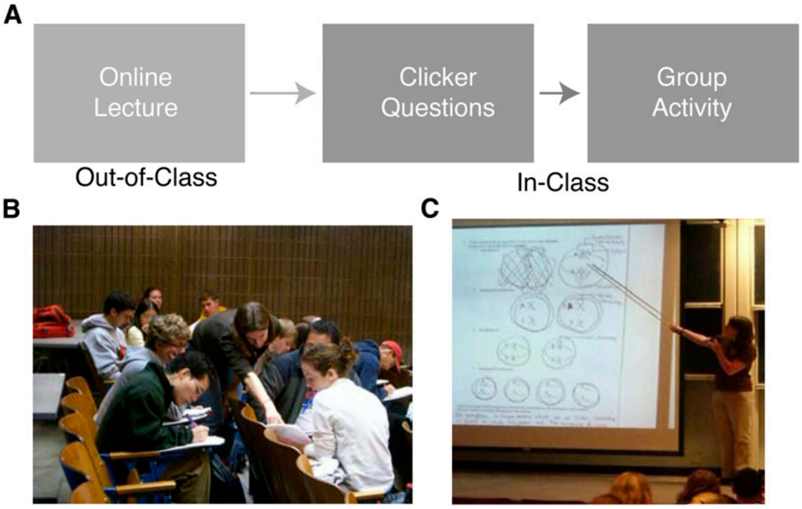

Figure 1 Hybrid course model. (A) Students were assigned to view an online lecture before coming to class. In class, students answered a series of clicker question to assess whether they could demonstrate the learning objectives associated with the online lectures and then participated in group activities designed to build critical thinking skills. (B) Instructor aiding a group of students with an in-class activity. (C) Presentation of the students' solution to the cell division in-class activity.

of the class period included a discussion where students presented their solutions to the class, using a document camera.

The information from the group worksheets was assessed on the examination and students received points toward their overall grade for participating in the in-class activities. For two of the class periods, we gave the students the choice between viewing the instructor-produced online lecture and/or doing an equivalent reading. We surveyed students to find out which of the resources they chose to use to prepare for class. Further information, regarding student use of and attitudes toward the online lectures, was collected at the end of the course survey.

Results

We implemented a hybrid course model into an introductory biology course. Students viewed online lectures before coming to class and then participated in activities in class (Figure 1A). Instructors spent between 3 and 5 hr developing online lectures, which provided students with the basic facts. The online lectures for the cell division unit included an introduction to what occurs during each of the stages of mitosis and meiosis. At the beginning of the class period, students answered five clicker questions testing student understanding of the material covered in the online lectures. Groups of students then worked with the instructor to create drawings integrating information from the lectures with fundamental genetics concepts. These in-class activities allowed the instructors to help the students build a conceptual framework and to elicit and discuss student misconceptions.

Use of online lectures

Students were surveyed at the beginning of the class period to determine whether they viewed the online lecture. Over the 5 years that we have used this model, we have found that between 70% and 85% of students viewed the online lecture before coming to class and that 97–99% of students plan on viewing the lectures before the examination. When students were asked why they did not view the online lecture before coming to class, the most common response was that they did not have enough time due to other coursework.

Achievement of learning objectives from online lectures

During the class period, we used clickers to assess whether students attained the learning objectives associated with the online, preclass lecture. Responses to questions that tested lower-order cognitive skills, such as knowledge and comprehension, indicated that students who viewed the online lectures performed better than those who had not viewed them; five of the seven questions reached statistical significance ($P < 0.05$) (Figure 2). Results from the five questions that focused on the higher-order cognitive skills (application and analysis), however, showed no difference in performance between the students who had and had not viewed the online lecture. These results support the idea that the online lectures helped the students to achieve the lower-order cognitive skills, but that the online lectures were not sufficient for the students to demonstrate the higher-order cognitive skills.

Identification of student misconceptions during in-class activities

To help the students to develop higher-order cognitive skills, the rest of the class period was devoted to group problem-solving activities and reporting out, with instructor facilitation as needed (Figure 1, B and C). During the group work time, students continually modified their responses as they gathered more information and solved the problems at hand. For the cell division unit, students drew a heterozygous, diploid cell, which they showed undergoing mitosis and meiosis, and then were asked to use their diagram to illustrate independent assortment of alleles. The heavily edited student worksheets (Figure S3) illustrate how students' answers were evolving during the activity—indicators of their problem-solving skills and application of their knowledge. Instead of lecturing, instructors were available to clarify

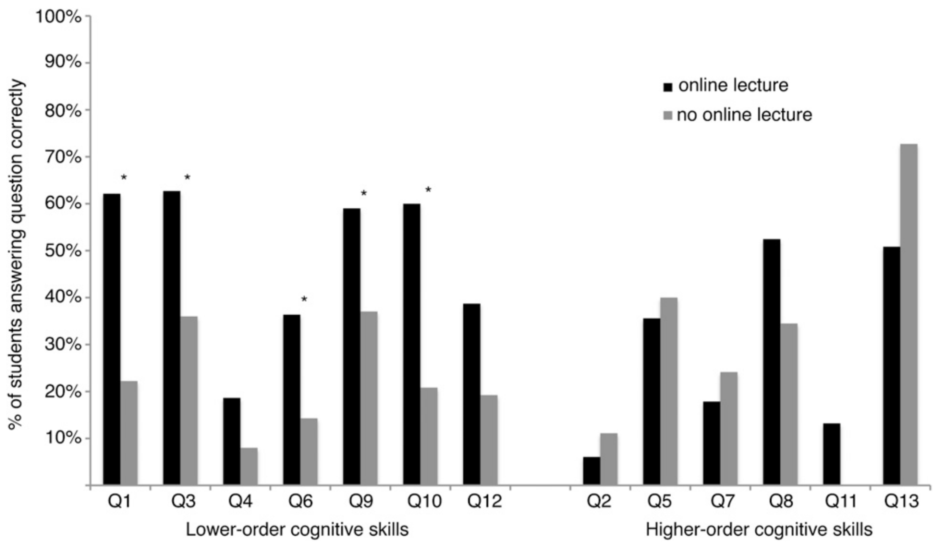

Figure 2 Students who viewed the online lecture before class performed better on the questions designed to test lower-order cognitive skills. For each clicker question the number of students that answered the question correctly was grouped by whether the students had viewed the online lecture before coming to class. The seven clicker questions on the left side were designed to test lower-order cognitive skills and the final six questions were designed to test higher-order cognitive skills. Clicker questions showing a statistically significant difference (P-value <0.05) between students viewing the online lecture and those students who did not view the corresponding lecture are indicated with an "*".

instructions and to address student misconceptions. Common misconceptions that we identified during the cell division unit are included in Figure S2.

Value of the online lectures

Students' answers to survey questions support that the students valued the online lectures as a learning tool. We found that 95–98% of students reported that the online lectures were helpful or very helpful toward the completion of that day's in-class activities. Most of the students reported attentively viewing the online lectures with only 6% reporting that they watched the online lecture while doing other things. We found that the students preferred viewing the online lecture over doing an out-of-class reading, with <5% choosing to do the reading instead of viewing the online lecture and 85% of the students viewing the online lecture before coming to class.

At the end of the course survey, students responded to an open-ended question to relate the value of the online lectures to their learning: 64% of students' comments were positive, 26% were mixed, and 10% were negative. A representative example of a positive quote illustrates how students valued the paired online lecture and in-class activity: "It let us learn the information and then apply those new concepts in in-class activities." The students' comments identified additional advantages of the online lectures. One student noted, "I also liked the ability to pause and digest the material at my own pace." Another pointed out that the pairing was "Very helpful because I could watch the online lecture at my own time (*i.e.*, 4:30 AM) and could use the online lecture to review confusing information." These comments indicate that the online lectures allow the students to learn the information at their own pace.

A low percentage of students had negative comments regarding the incorporation of the online lectures. One concern was the length of the online lectures. The students preferred that the length of online lectures be limited to ≤20 min to maximize student engagement. This prompted us to create two lectures, one on mitosis and one on meiosis, for the cell division unit. An additional concern was a perception that the online lectures significantly increased the student workload outside of class. To address this concern, we compared the number of hours students reported spending outside of the class each week to the number of hours estimated in the previous year. The only major change between the 2 years was the addition of online lectures. We found no significant difference in student reported workload in years with or without online lectures. In both cases, 75% of students reported spending <6 hr per week studying for the course, which contradicts the perception that the online lectures increased workload outside class time.

Discussion

Students used and valued online lectures in an introductory biology course. Students who viewed the online lectures before class performed better on lower-order cognitive learning objectives. Moving content from the class period to the online format allowed instructors to use class time to help students achieve the higher-order cognitive learning objectives and to assess student understanding of essential concepts. The curriculum restructuring did not reduce the amount of course content or alter the amount of time students reported spending on the course. The results of this study support the implementation of a hybrid course model, combining online lectures with in-class group problem solving.

Like others, we found the online format offers benefits not found in traditional lectures, including the flexibility for students to view and review the lectures at their convenience (Cardall *et al.* 2008). Instructors also appreciate the increased flexibility offered by online learning (Mayadas *et al.* 2009). A meta-analysis of online learning from the Department of Education suggests that students perform well in online learning situations and even better when online learning was paired with face-to-face instruction (Office of Planning, Evaluation, and Policy Development 2010).

TABLE I Tips for effective development and implementation of a hybrid course

Maximize student engagement
1. Align online lectures and in-class activities with the course learning goals.
2. Keep the online lectures short (15–20 min).
3. Post online lectures at least 2 days prior to the in-class activity.
4. Use clickers to assess whether students have achieved the learning objectives associated with the online lectures and follow challenging questions with peer discussion.
5. Use in-class group work to extend the students' conceptual understanding of the material and to address students' misconceptions.
6. Hold students accountable for material in the online lectures and in-class activities on summative assessments.

Minimize instructor input
1. Create slides and record lecture using PowerPoint.
2. Use online lectures with a subset of the class periods.
3. Choose topics from less rapidly evolving fields so the same presentation or a minimally modified presentation can be used for multiple years.

Therefore, we promote combining online and in-class learning activities and outline recommendations for effective development and implementation of a hybrid course curriculum in Table 1.

The success of active learning is associated with effective pedagogical approaches to curricular design (Andrews *et al.* 2011). We took a constructivist approach to active learning, accepting that students must integrate new information with their existing knowledge frameworks (Chi 2009). We designed the in-class worksheets to identify common student misconceptions and to emphasize conceptual frameworks rather than isolated facts. During the implementation phase, students presented multiple answers to the worksheets. By comparing and contrasting answers, we were able to appropriately address student misconceptions. Addressing these misconceptions was critical because the subsequent topics in the course built upon information covered in these units. Instructors emphasized that the skills students were developing during the in-class activity would be assessed on the course examinations. This is one strategy that has been reported to help address student resistance to curricular change (Silverthorn 2006).

Our study has several limitations. We did not assess whether the hybrid model was associated with learning gains or improved retention; however, other researchers have established these benefits of small group learning (Springer *et al.* 1999). Students in this study selectively enrolled in the honors course knowing that participation in the curriculum would require active learning and group problem solving. Students in this course may have different abilities and motivation levels than other class populations, which may limit the generalizability of this study.

Curricular innovations are rarely effective in all situations (Tanner 2011). Instructors must modify the model to meet the needs of their student population, classroom environment, and resources. One addition to the hybrid model, implemented in a computer science course, was to have students complete an online, graded quiz after viewing the online lecture. The quiz motivated students to view the lectures and helped the instructor to identify topics requiring additional coverage during the class period (Moses and Litzkow 2005).

In conclusion, there are meaningful benefits associated with curricular redesign that integrates online lectures and in-class active learning exercises. This hybrid course model allows instructors to effectively identify student misconceptions of key concepts and to devote in-class time to developing students' higher-order cognitive skills.

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Literature Cited

Allen, D., and K. Tanner, 2005 Infusing active learning into the large enrollment biology class: seven strategies, from simple to complex. CBE Life Sci. Educ. 4: 262–268.

American Association for the Advancement of Science, 2011 *Vision & Change in Undergraduate Biology Education: A Call to Action*. American Association for the Advancement of Science, Washington, DC.

Andrews, T. M., M. J. Leonard, C. A. Colgrove, and S. T. Kalinowski, 2011 Active learning not associated with student learning in a random sampling of college biology courses. CBE Life Sci. Educ. 10: 394–405.

Batzli, J. M., 2005 A unique approach? Four semesters of biology core curriculum. CBE Life Sci. Educ. 4: 125–128.

Buncick, M. C., P. G. Betts, and D. D. Horgan, 2001 Using demonstrations as a contextual road map: enhancing course continuity and promoting active engagement in introductory college physics. Int. J. Sci. Educ. 23: 1237–1256.

Cardall, S., E. Krupat, and M. Ulrich, 2008 Live lectures *vs.* video-recorded lecture: Are students voting with their feet? Acad. Med. 83(12): 1174–1178.

Chi, T. H. M., 2009 Active-constructive-interactive: a conceptual framework for differentiating learning activities. Topics Cogn. Sci. 1: 73–105.

Crowe, A., C. Dirks, and M. P. Wenderoth, 2008 Biology in bloom: implementing Bloom's taxonomy to enhance student learning in biology. CBE Life Sci. Educ. 7: 368–380.

Deslauriers, L., E. Schelew, and C. Wieman, 2011 Improved learning in a large-enrollment physics class. Science 332(6031): 862–864.

Dikmenli, M., 2010 Misconceptions of cell division held by student teachers in biology: a drawing analysis. Sci. Res. Essay 5(2): 235–247.

Ebert-May, D., and J. Hodder, 2008 *Pathways to Scientific Teaching. Ecological Society of America*. Sinauer Associates, Sunderland, MA.

Felder, R. M., 1993 Reaching the second tier: learning and teaching styles in college science education. J. Coll. Sci. Teach. 23: 286–290.

Foertsch, J., G. Moses, J. Strikwerda, and M. Litzkow, 2002 Reversing the lecture/homework paradigm using eTEACH web-based streaming video software. J. Eng. Educ. 91: 267–274.

Grabe, M., and K. Christopherson, 2008 Optional student use of online lecture resources: resource preferences, performance and lecture attendance. J. Comput. Assist. Learn. 24: 1–10.

Handelsman, J., D. Ebert-May, R. Beichner, P. Bruns, A. Chang *et al.*, 2004 Policy forum: scientific teaching. Science 304: 521–522.

Handelsman, J., S. Miller, and C. Pfund, 2007 *Scientific Teaching*. W. H. Freeman, New York.

Klymkowsky, M. W., K. Garvin-Doxas, and M. Zeilik, 2003 Bioliteracy and teaching efficacy: what biologists can learn from physicists. Cell Biol. Educ. 2: 155–161.

Knight, J. K., and W. B. Wood, 2005 Teaching more by lecturing less. Cell Biol. Educ. 4: 298–310.

Levesque, A. A., 2011 Using clickers to facilitate development of problem-solving skills. CBE Life Sci. Educ. 10(4): 406–417.

Marbach-Ad, G., and R. Stavy, 2000 Students' cellular and molecular explanations of genetic phenomena. J. Biol. Educ. 34: 200–205.

Mayadas, A. F., J. Bourne, and P. Bacsich, 2009 Online education today. Science 323: 85–89.

McFarlin, B. K., 2008 Hybrid lecture-online format increases student grades in an undergraduate exercise physiology course at a large urban university. Adv. Physiol. Educ. 32: 86–91.

Miller, S., C. Pfund, C. M. Pribbenow, and J. Handelsman, 2008 Scientific teaching in practice. Science 322: 1329–1330.

Moses, G., and M. Litzkow, 2005 In-class active learning and frequent assessment reform of nuclear reactor theory course, F1C-26 35th ASEE/IEEE Frontiers in Education Conference, Indianapolis, IN.

National Research Council, 2000 *How People Learn: Brain, Mind, Experience, and School, Expanded Edition*, edited by J. D. Bransford, A. L. Brown, and R. R. Cocking. National Academy Press, Washington, DC.

National Research Council, 2003 *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics*, edited by M. A. Fox, and N. Hackerman. National Academy Press, Washington, DC.

Office of Planning, Evaluation, and Policy Development, 2010 *Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies*. Department of Education, Washington, DC.

Phillips, A. R., A. L. Robertson, J. M. Batzli, M. A. Harris, and S. Miller, 2008 Aligning goals, assessments, and activities: an approach to teaching PCR and gel electrophoresis. CBE Life Sci. Educ. 7: 96–106.

Silverthorn, D. U., 2006 Teaching and learning in the interactive classroom. Adv. Physiol. Educ. 30: 135–140.

Springer, L., M. E. Stanne, and S. S. Donovan, 1999 Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: a meta-analysis. Rev. Educ. Res. 69(1): 21–51.

Tanner, K., 2011 Reconsidering "what works". CBE Life Sci. Educ. 10: 329–333.

Udovic, D., D. Morris, A. Dickman, J. Postlethwait, and P. Wetherwax, 2002 Workshop biology: demonstrating the effectiveness of active learning in a non-majors biology course. Bioscience 52: 272–281.

Vatovec, C., and T. Balser, 2009 Podcasts as tools in introductory environmental studies. J. Microbiol. Biol. Educ. 10: 19–24.

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Figure S1 Clicker questions and their associated learning objectives and Bloom's level

Mitosis and Meiosis questions

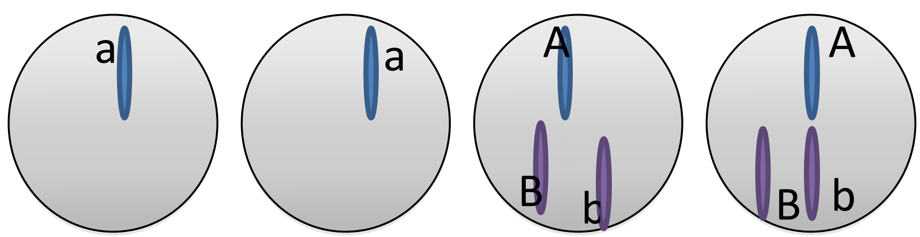
Q1: Which of the following events does not occur during mitosis?
A.Breakdown of the nuclear envelope
B.Daughter cells are genetically identical
C.Condensation of the chromosomal DNA
D.Pairing of homologous chromosomes
E.All of these events occur during mitosis
Learning Objective: Differentiate between mitosis and meiosis
Bloom's: Comprehension- lower-order cognitive skill

Q2: If a dog cell has 39 chromosome pairs,
how many sister chromatids are present in G2?
A.38
B.39
C.76
D.78
E.156
Learning Objective: Predict how the DNA content changes during the cell cycle in a nonhuman species.
Bloom's: Application- higher-order cognitive skill

Q3: At which stage in meiosis does pairing of homologous chromosomes occur?
A. Prophase I
B. Anapase I
C. Prophase II
D. Anaphase II
E. I don't know
Learning Objective: Identify what occurs during each of the stages of meiosis
Bloom's: Knowledge- lower-order cognitive skill

Q4: At which stage in meiosis does independent assortment of alleles occur?
A. Prophase I
B. Anapase I
C. Prophase II
D. Anaphase II
E. I don't know
Learning Objective: Identify at which step in meiosis the homologous chromosomes separate from each other.
Bloom's: Comprehension- lower-order cognitive skill

Q5: A diploid cell heterozygous for Genes A and B has an error in chromosome segregation during meiosis (nondisjunction) leading to the production of the following gametes:



At which step in meiosis was there a problem?
A. Prophase I
B. Anaphase I
C. Prophase II
D. Anaphase II
E. Can't determine
Learning Objective: Given a set of unbalanced gametes, predict during which stage in meiosis there was a segregation defect.
Bloom's: Application- higher-order cognitive skill

Recombination Questions

Q6 Which of the following statements about recombination is incorrect

A.Genetic maps of chromosomes are based on the average number of crossovers during meiosis
B.The recombination frequency will overestimate the genetic distance
C.One crossover event can interfere with another crossover event
D.Tightly linked genes will have a recombination frequency close to 0
E.All of the statements are correct
Learning Objective: Recognize that recombination frequency underestimates the genetic distance
Bloom's: Knowledge- lower-order cognitive skill

Q7 A female fly with long wings and a gray body, heterozygous for genes controlling body color and wing length, was crossed to a homozygous recessive mutant male with vestigial wings and black body generating the following progeny:

Long wings, Gray body	23 flies
Vestigial wings, Black body	26 flies
Long wings, Black body	124 flies
Vestigial wings, Gray body	127 flies

You interpret this to mean that
A.The genes are unlinked since the parental phenotypes are rare
B.The mother fly received the dominant allele for body from one parent and the dominant allele for wings from the other parent.
C.The genes for body and wings are on opposite ends of the chromosomes
D.The mother fly received the dominant alleles for body and wings from the same parent
E.I don't know
Learning Objective: Predict the parental genotypes given the phenotypes of the offspring
Bloom's: Application- higher-order cognitive skill

Probability and Pedigrees Questions
Q8 After completing a trihybrid genetic cross, you propose a model suggesting that the phenotypes of your progeny can be explained by three genes each with 2 alleles one dominant over the other.
How would you test your hypothesis?
A.Calculate Chi-squared value
B.Calculate the recombination frequency between each gene
C.Use the Binomial Probability formula
D. Draw a Punnett Square
E. Don't know
Learning Objective: Choose the appropriate test to evaluate a genetic model.
Bloom's: Application- higher-order cognitive skill

Q9 You cross two yellow mice and produce a mixture of yellow and agouti progeny. You propose a model predicting 3 yellow mice for every 1 agouti mouse. Do you reject your hypothesis after calculating a $\chi 2$ statistic of 5.143?

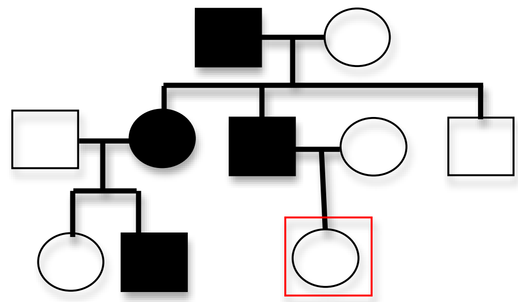
Degree of Freedom	5% Critical Value
1	3.841
2	5.991

A. Reject since $\chi 2$ is above the 5% critical Value for 1 Degree of Freedom
B. Don't reject since $\chi 2$ is above the 5% critical Value for 1 Degree of Freedom
C. Reject since $\chi 2$ is below the 5% critical value for 2 degrees of freedom
D. Don't reject since $\chi 2$ is below the 5% critical Value for 2 Degree of Freedom
E. I don't know
Learning Objective: Know the criteria for rejection of the $\chi 2$ statistic
Bloom's: Comprehension- lower-order cognitive skill

Q10 If an individual is homozygous for a recessive trait and has children with a carrier for the trait. What is the probability that they will have one affected child and 2 unaffected children?
A. 0

B. 1/8
C. ½
D. [(3!)/(2!1!)]X(1/2)^{2}(1/2)^{1}]
E. Can't determine
Learning Objective: Identify the binomial formula as the correct way to predict
Bloom's: Knowledge- lower-order cognitive skill

Q11 Assume the trait shown in the pedigree is very rare. What is the probability that the individual in the red box carries the mutant allele causing the trait?



A.0
B. ¼
C. ½
D. [(5!)/(3!2!)]X(1/2)^{3}(1/2)^{2}]
E. Can't determine
Learning Objective: Interpretation of pedigrees and use of information to determine if an individual in the pedigree is a carrier
Bloom's: Application- higher-order cognitive skill

Quantitative Genetics Questions
Q12 After intercrossing the F1 produced from a cross between two inbred strains, which of the following statements about the F2 offspring is incorrect
A. **The F2 with show increased hybrid vigor over the F1.**
B. The F2 will show a decrease in heterozygosity from the F1.
C. The F2 may exhibit inbreeding depression.
D. The variance of the F2 population will be greater than the variance of the F1 population.
E. I don't know.
Learning Objective: Recognize that increased heterozygosity will result in an increase in hybrid vigor.
Bloom's: Comprehension- lower-order cognitive skill

Q13 In one study, the heritability of IQ is determined to be .7.
This means that
A. In an individual, 70% of intelligence is due to genetic factors and 30% is due to environmental factors
B. No matter what environment you are in the heritability will be 70%
C. **70% of the variation in IQ seen in the population is due to genetic factors**
D. 70% of the average of two parents' IQs will be equal to the mean IQ of their offspring
E. All of the above
Learning Objective: Evaluate what heritability means.
Bloom's: Analysis- higher-order cognitive skill

Figure S2 Sample in-class activity worksheet

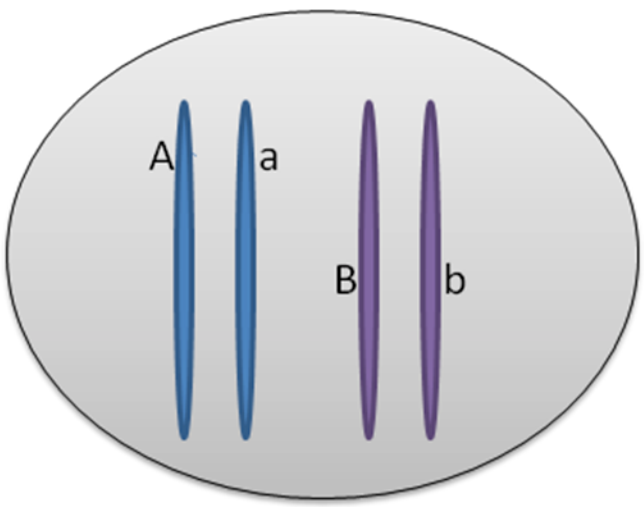
Group #:
Group Name:
Facilitator: Monitor:
Recorder: Reporter:

Cell Division worksheet

Today's exercise is about understanding the mechanisms of mitosis and meiosis. Learning how these processes work sets the foundation for understanding much of genetics.

Directions:
Each group needs to draw their answers to the following questions. Different color pens or pencils should be used to indicate different chromosomes and alleles should be labeled in each of the diagrams. Each group should turn in one copy of the worksheet at the end of the class period.

1. A diploid cell contains two sets of chromosomes and is heterozygous for a gene (containing alleles A and a) on chromosome one and is heterozygous for a gene (containing alleles B and b) on chromosome two. Draw this cell in G1 labeling the alleles on the chromosomes.

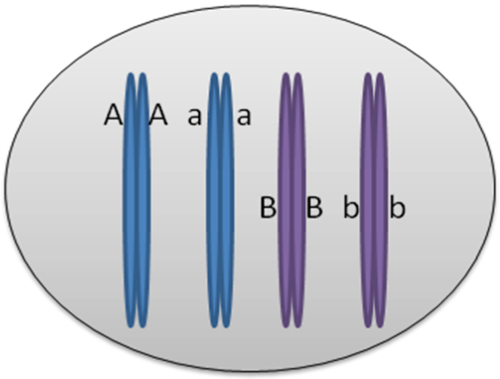


*A **good** answer is similar to the neighboring diagram including four chromosomes and the A and a on the same color chromosomse and B and b on the other color chromosomes. The total DNA content should be 2C. **Excellent** answers include drawing the chromosomes in a nucleus and indicating prior to mitosis the chromosomes would be decondensed. **Poor** answers will not have the correct number of chromosomes, will have the alleles labeled on the same chromosome, will show the chromosomes in a replicated state as an X, or will show the homologous chromosomes physically touching.*

2. This cell receives cues to duplicate itself.

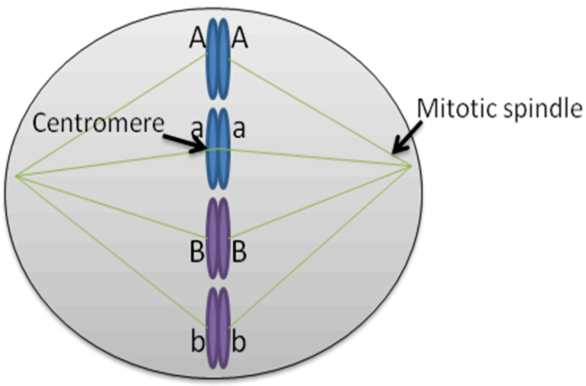
Draw your cell at the following stages:

- G2 just after DNA replication prior to mitosis



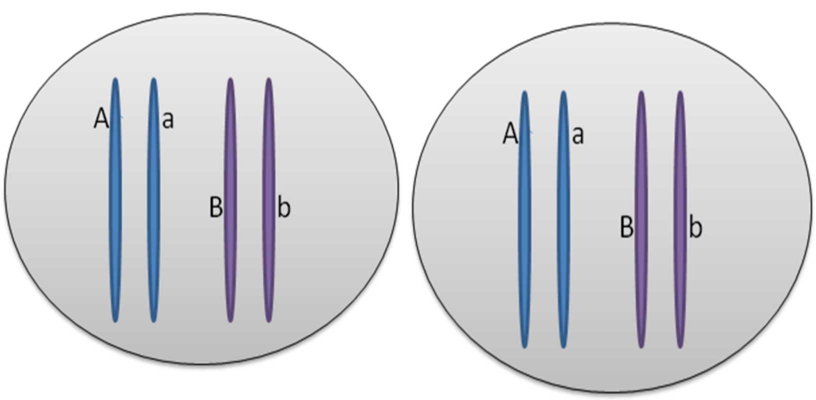
*For **good** answers, students should have a total of 8 chromatids with each allele being present on the adjacent sister chromatids. The DNA content is 4C. **Excellent** answers will include an intact nuclear envelope and indicate that the chromosomes are still decondensed. **Poor** answers will label the sister chromatids with different alleles, will not have the sister chromatids physically touching, do not show duplication of the genetic material, or will already show the chromosomes entering into mitosis (aligning along the metaphase plate).*

- Metaphase (Mitosis)



*For a **good** answer, the students will show the chromosomes aligned along the metaphase plate and have the mitotic spindle and centromere labeled and 4C DNA content. **Excellent** answers will indicate nuclear envelope breakdown has occurred and chromatin condensation has happened. **Poor** answers will include a loss in the total number of chromatids from the previous section, will have the chromosomes rotated 90 degrees, or will pair the homologous chromosomes along the metaphase plate.*

- After cytokinesis (Mitosis)

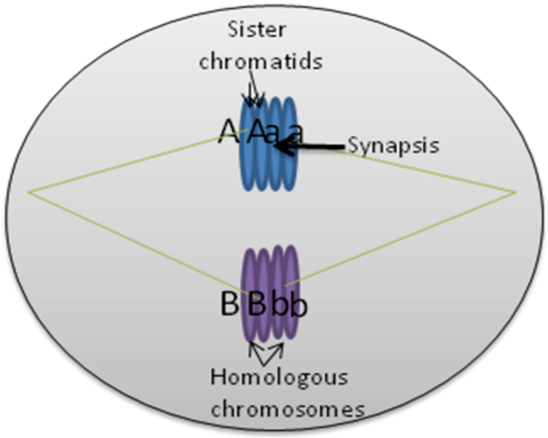


***Good** answers will diagram two identical cells the same as the cell in question 1. The DNA content of each cell is 2C. **Excellent** answers indicate that the DNA is now decondensed and the nuclear envelope has reformed. **Poor** answers will show daughter cells containing different genotypes and chromosome composition from the parent cell or will label the chromosomes as sister chromatids.*

Label your pictures with terms such as centromeres and mitotic spindle. What is the DNA content (C) at each of these stages?

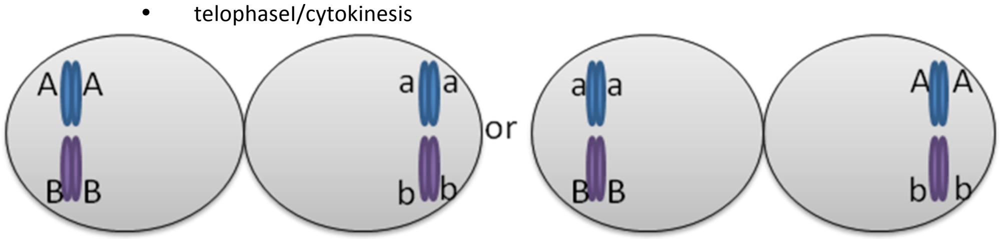
3. Your original cell (in question 1) enters **meiosis**.
   Draw your cell at the following stages:

- metaphase I



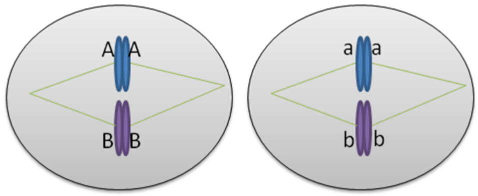
Good *answers will pair homologous chromosomes on the metaphase plate and successfully indicate sister chromatids, homologous chromosomes, and synapsis.* ***Excellent*** *answers will indicate diagram recombination at the synapse and show appropriate genetic exchange of the alleles.* ***Poor*** *answers will not include the pairing of homologous chromosomes but instead show alignment similar to what occurs in metaphase during mitosis. Some students will quadruple rather than double the DNA content, will label the connection between sister chromatids as the synapse, or will mislabel the sister chromatids and homologous chromosomes.*

- telophaseI/cytokinesis

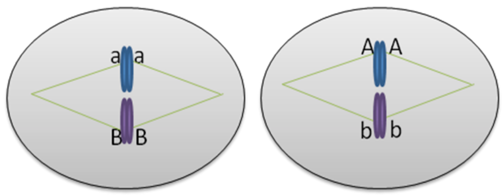


Good *answers will have the homologous chromosomes separated to opposite poles with each new cells containing two sister chromatids of each chromosome.* ***Excellent*** *answers will diagram both potential results and explain that according to the principle of independent assortment the alleles will segregate independently.* ***Poor*** *answers with have cells lacking one of the chromosomes or containing two different alleles in each of the daughter cells assuming no recombination has taken place (i.e. Aa).*

- metaphase II

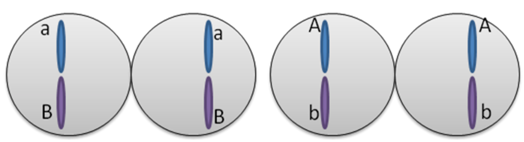


or

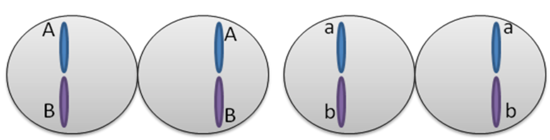


Good *answers will show two of the daughter cells from meiosis I with the sister chromatids of the same allele aligning along the metaphase plate.* ***Excellent*** *answers will include the mitotic spindles and both scenarios depending on independent assortment.* ***Poor*** *answers will most likely occur if there were mistakes in the students' diagram of meiosis I and may include having A and a paired on the metaphase plate.*

- telophaseII/cytokinesis.

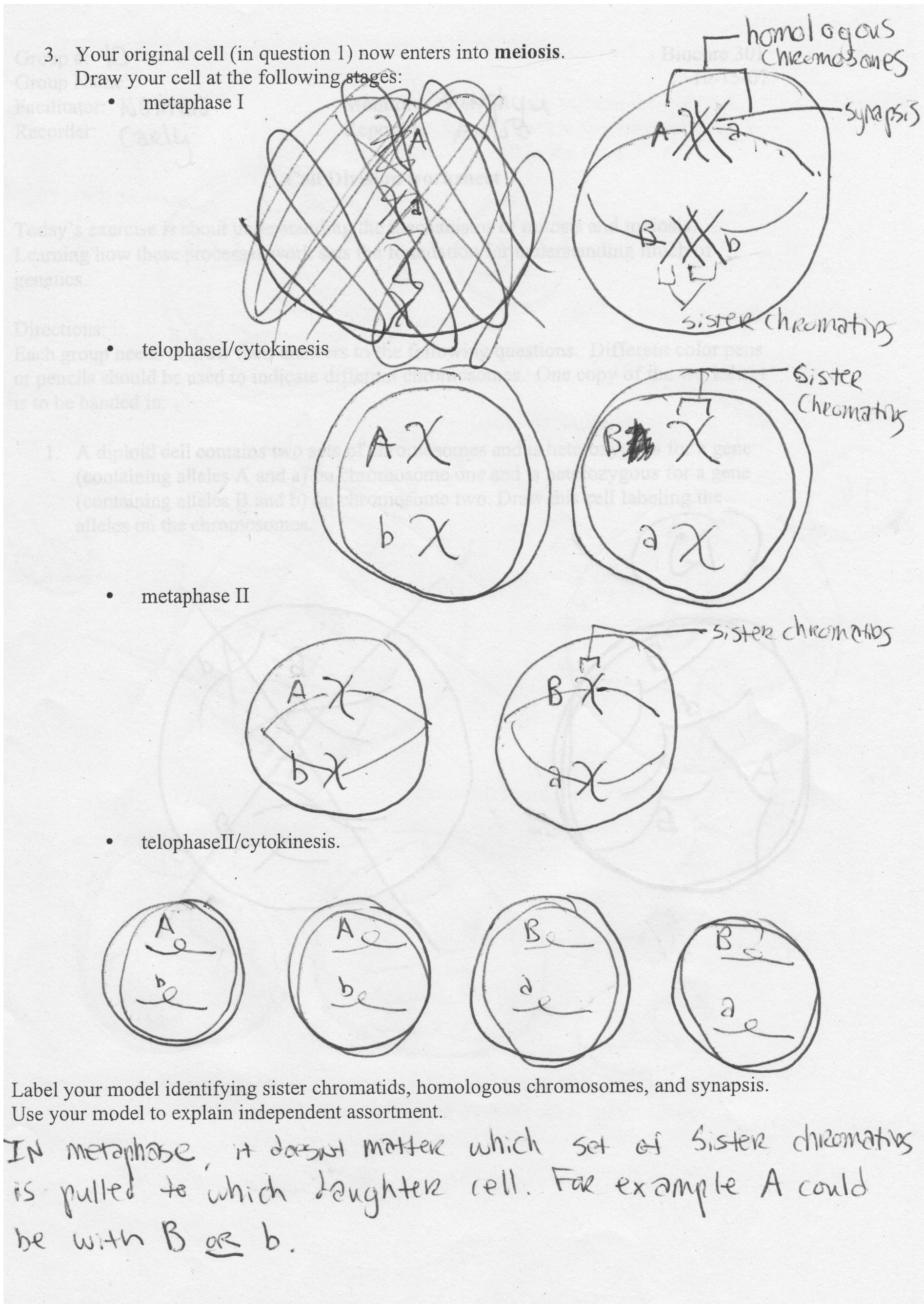


or



*G**ood*** *answers will show four daughter cells each with half the DNA content (1C) of the original cell.* ***Excellent*** *answers will indicate that due to independent assortment you will generate daughter cells that contain AB and ab or daughter cells that are Ab and aB.* ***Poor*** *answers will not contain half the DNA content of the parent cells and will not have four daughter cells.*

Label your model identifying sister chromatids, homologous chromosomes, and synapsis. Use your model to explain independent assortment.



3. Your original cell (in question 1) now enters into **meiosis**.
Draw your cell at the following stages:

- metaphase I

homologous chromosomes

synapsis

sister chromatids

- telophaseI/cytokinesis

Sister Chromatids

- metaphase II

sister chromatids

- telophaseII/cytokinesis.

Label your model identifying sister chromatids, homologous chromosomes, and synapsis.
Use your model to explain independent assortment.

IN metaphase, it doesnt matter which set of sister chromatids is pulled to which daughter cell. For example A could be with B or b.

Figure S3 Student completed cell division worksheet