NONDISJUNCTION IN MEIOSIS: A FOUR-PART KINESTHETIC MODELING ACTIVITY

Subject/Problem

Meiosis is a fundamental concept in biology because it provides the basis for understanding inheritance, genetic variation, and chromosomal disorders. Students frequently confuse the two meiotic divisions and struggle to predict the consequences of chromosomal segregation errors, including the outcomes of nondisjunction (Newman et al., 2012). One of the most challenging concepts is differentiating between nondisjunction in Meiosis I and Meiosis II. Although both produce aneuploid gametes, Meiosis I nondisjunction results in four abnormal gametes, whereas Meiosis II nondisjunction produces two abnormal and two normal gametes. Understanding these different outcomes is essential for explaining the chromosomal basis of conditions such as Down syndrome (Trisomy 21), Turner syndrome, and Klinefelter syndrome.

Physical model-based activities have been shown to produce greater learning gains than other active-learning strategies when teaching abstract cellular processes (Newman et al., 2018). Although kinesthetic modeling activities have been used to teach meiosis (Hubbs et al., 2017; Newman & Wright, 2017; LaFountain & Rickards, 2022), few published instructional activities focus specifically on helping students differentiate between nondisjunction in Meiosis I and Meiosis II. Furthermore, few studies have evaluated meiosis modeling activities using matched pre- and post-assessments across multiple undergraduate biology courses. This study evaluates a four-part kinesthetic chromosome modeling activity designed specifically to address this misconception.

Design or Procedure

The study included 32 undergraduate biology students: 20 enrolled in Biology for Science Majors I and 12 enrolled in an upper-division Genetics course. Students in the Genetics course had previously completed Biology for Science Majors I as a prerequisite. Both groups received lecture instruction on meiosis prior to participating in the activity.

Both implementations used an identical five-item multiple-choice pre/post assessment administered through Microsoft Forms immediately before and after the activity, allowing direct comparison of individual student performance. Assessment items measured students' understanding of the mechanisms and outcomes of nondisjunction in Meiosis I and Meiosis II, the meiotic stages at which these errors occur, and chromosome behavior during normal meiosis. Scores ranged from 0 to 5.

The activity consisted of four scaffolded parts, with each part building on the previous one to progress from normal meiosis to increasingly complex chromosome segregation errors. Students first modeled normal meiosis as a conceptual baseline before modeling nondisjunction during Meiosis I and Meiosis II, allowing them to directly compare how errors at each stage affect gamete outcomes. Students compared the resulting gametes to determine that Meiosis I nondisjunction produces four abnormal gametes, whereas Meiosis II nondisjunction produces two normal and two abnormal gametes. The fourth part extended the activity to sex chromosome nondisjunction, connecting chromosome segregation errors to conditions such as Turner syndrome (XO) and Klinefelter syndrome (XXY).

Using color-coded pipe cleaners as chromosome models, students physically modeled chromosome behavior, photographed each stage of meiosis, and completed seven guided discussion questions that emphasized mechanistic reasoning over memorization. The discussion questions prompted students to explain chromosome behavior, justify their predictions, and

connect chromosome segregation errors to their biological and clinical consequences. The activity required only pipe cleaners and was completed during a single 50-minute class period.

Analyses and Findings

Pre- and post-activity assessment scores (maximum = 5) were compared using paired-samples t-tests for each course and for the combined sample. In Biology for Science Majors I (n = 20), mean scores improved from 4.00 (SD = 1.21) to 4.90 (SD = 0.31), a statistically significant gain ($t(19) = 3.45$, $p = .003$, $d = 0.77$). In the Genetics course ($n = 12$), mean scores improved from 3.58 (SD = 1.51) to 4.92 (SD = 0.29), a statistically significant gain ($t(11) = 2.97$, $p = .013$, d = 0.86). Across the combined sample ($N = 32$), mean scores improved from 3.84 ($SD = 1.32$) to 4.91 (SD = 0.30), a statistically significant gain ($t(31) = 4.56$, $p < .001$, $d = 0.81$). Sixteen students improved their scores from pre- to post-assessment, while the remaining 16 maintained scores of four or five. No student's score declined following the activity.

Item-level analyses demonstrated consistent improvement across all five assessment items in both courses. In Biology for Science Majors I, the largest gains occurred on questions assessing the mechanisms of Meiosis I nondisjunction (75% to 95%), Meiosis II nondisjunction (80% to 100%), and chromosome behavior during Meiosis I (75% to 95%). Items assessing the outcomes of nondisjunction and the meiotic stage in which the error occurs reached 100% post-assessment accuracy. In the Genetics course, the largest gains occurred on questions assessing the Meiosis I mechanism (67% to 100%), the outcomes of nondisjunction (67% to 100%), and the meiotic stage in which nondisjunction occurs (58% to 92%). Across the combined sample, post-assessment accuracy ranged from 92% to 100% for all five items.

The largest improvements occurred on assessment items targeting the primary instructional focus of the activity: differentiating between nondisjunction in Meiosis I and Meiosis II and predicting the resulting gamete outcomes. These findings indicate that the activity successfully addressed the specific misconception identified in the Subject/Problem while improving students' overall understanding of chromosome segregation during meiosis.

Contribution

This study introduces a four-part instructional activity designed specifically to address one of the most persistent misconceptions in undergraduate genetics: differentiating between nondisjunction in Meiosis I and Meiosis II. Unlike previously published meiosis modeling activities (Hubbs et al., 2017; Newman & Wright, 2017; LaFountain & Rickards, 2022), this activity focuses specifically on comparing the mechanisms and outcomes of these two segregation errors. The four-part sequence intentionally builds from normal meiosis to progressively more complex nondisjunction scenarios, allowing students to visualize chromosome behavior, compare resulting gametes, and connect chromosome segregation errors to human chromosomal disorders.

The activity also provides a practical resource for biology educators. It requires only inexpensive materials, can be completed during a single class period, and was successfully implemented in both an introductory biology course and an upper-division genetics course. The observed learning gains suggest that the activity can improve student understanding of nondisjunction while remaining easy to incorporate into existing undergraduate biology curricula.

Future work will include implementation with additional course sections to increase sample size, evaluation of long-term retention of learning gains, and refinement of the activity and assessment instrument based on student performance. Activity materials, assessment instrument,

and guided discussion questions are available for educators interested in implementing the activity in their own biology courses.

General Interest

Meiosis, chromosome segregation, and nondisjunction are fundamental topics in biology, making this presentation relevant to instructors teaching introductory biology, cell biology, genetics, and Advanced Placement Biology. The presentation highlights a classroom-tested activity that addresses a persistent student misconception by providing a structured, hands-on approach for differentiating between nondisjunction in Meiosis I and Meiosis II while connecting chromosome segregation errors to human chromosomal disorders.

The presentation will include a condensed demonstration of the activity, allowing attendees to experience the instructional sequence before reviewing the assessment data and discussing classroom implementation. Participants will receive the complete activity, assessment instrument, and guided discussion questions, along with practical strategies for implementing and adapting the activity in their own courses.

References

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