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Chromosome structure worksheet pdf

These are homework exercises to accompany Nickle and Barrette-Ng's TextMap Online Open Genetics. Genetics is the scientific study of inheritance and variation of inherited properties. It involves studying genes themselves, how they work, interacting and producing the visible and measurable properties that we see in individuals and populations of species as they change from one generation to the next, over time, and in different environments. Create diagrams that show how an improper crossover event during meiosis can cause the following factors: (a) an inversion or (b) a translocation. Create a diagram showing how a non-disjunction event can lead to a child with a 47,XYY karyotype. How many Barr bodies would you expect in cells from people who are: (a) 46, XY, (b) 46.XX, (c) 47, XYY, (d) 47,XXX, (e) 45,X, and (f) 47,XXY ? Why can people with trisomy-21 (47,sex,+21) survive, but not with monosomy-21 (45,sex,-21)? When Drosophila geneticists want to produce mutant strains with deletions, they expose flies to gamma rays. What does this mean about gamma rays? What would happen if there was a nondisjunction event with chromosome 21 in a 46,XY zygote? Design a FISH-based experiment to find out if your lab partner is a 47.XXX female or a 47.XYY male. What would Figure 9.18 look like if it also showed metaphase chromosomes from another cell? Contributors and attributions In order to continue to enjoy our website, we ask you to confirm your identity as a human being. Thank you for your cooperation. Concept #1: Chromosome structurePractice: Which of the following terms is used to describe open chromatin, which is loosely packaged DNA? Practice: Histone proteins are responsible for this? Practice: Which of the following values is the correct order of chromosome packaging values? Practice: What is the name of the enzyme that removes supercoils in DNA? Chromosome structure and behavior are topics that are notoriously difficult for students to grasp, leading to gaps in the understanding of complex processes with chromosomes and inheritance. Genetics is a complicated subject based on a thorough understanding of the structure and molecular behavior of information-carrying chromosomes, and many students are struggling with this issue. Although teaching on chromosomes often begins in a middle school science class, students have difficulty understanding the process of meiosis; this phenomenon has been documented for more than 30 years (Johnstone and Mahmoud, 1980; Stewart and Dale. Stewart et al., 1990; Kindfield, 1991, 1994b; Dikmenli, 2010; Wright and Newman, 2011). Although this Widely recognized problem and many teaching approaches have been developed to try to solve it, little progress has been made and no systematic studies have been conducted to determine what students think when working on meiosis-related problems. The few studies have been published to focus on misunderstandings and not on basic knowledge and scaffolding. Deep-rooted misunderstandings about the complex processes of meiosis, cell division and genetics are well documented (Fisher et al., 1986; Brown. Kindfield, 1994a; Bahar et al., 1999; Lewis et al., 2000; Marbach-Ad, 2001; Dikmenli, 2010), with several studies highlighting the difficulties students have in explaining the molecular basis of inheritance (Marbach-Ad, 2001; Wood-Robinson et al., 2000). Although experts have identified several common misunderstandings and difficulties with the topics, it is not clear why students embrace these ideas or why it is so difficult to change their conceptual models. Concepts associated with cell division and meiosis are crucial for a clear understanding of many facets of life, including reproduction, cell biology, genetics, and evolution, but little has changed in the way these subjects are taught, and understanding has not improved (Dikmenli, 2010). Through a partnership between the National Society of Genetic Counselors and the American Society of Human Genetics, high school students from across the country participated in an essay writing competition as part of National DNA Day (Mills Shaw et al., 2008). A thorough analysis of 500 essays (out of the 2443 collected in the 2-year competition) revealed a very interesting finding: Students had the same genetic misunderstandings as students in 2007 (from a comparable study by the National Assessment of Educational Process), despite the expansion of genetic information and technology that took place during the same period. Unsurprisingly, inheritance patterns were the second most confusing topic for these high school students. In an example of higher education, out of 409 students who recently took a genetics course (several offers with multiple lecturers over the course of 2 years at a private college with a large enrollment), 74 students (18%) either withdrawn or failed the course (R. Rothman and M. Osier, personal communication). Two of the most common misconceptions by students about the meiotic cell division relate to the chromosome structure. In in-depth interviews with experts, experienced beginners and real beginners (students) on meiosis problems, Kindfield (1991, 1994a,b) documented that students often believe that the chromosome structure is a function of chromosome count or ploid. She argued that in order to understand the ploidie correctly, students must consider both reproducible and unreplicated as discrete entities, and suggested that the clearly identify the origin of two-DNA-molecule entities and clearly distinguish between the concepts of chromosome structure and the number of chromosomes in order to overcome cognitive stumbling blocks. Another common common is that the students mistakenly believe that two-DNA molecule chromosomes in diploid cells (formed by replication) are created by the fusion of two single DNA molecule chromosomes, one of each parent. This misunderstanding of fertilization education, which Smith first reported on in 1991, can severely affect students' ability to understand the main point of meiosis (to produce gametes for later fertilization steps). One result of such findings was the development of new learning assessment tools. The Geneticliteracy Assessment Instrument (GLAI; Bowling et al., 2008) has devoted eight of 31 questions to the topics examined in this manuscript: nature of genetic material and transmission. The Genetics Concept Assessment (GCA), another tool for assessing student learning gains in a typical college-level genetics course, has 11 out of 25 questions to assess whether students can properly describe the molecular anatomy of genes and genomes, mechanisms through which the genome of an organism is passed on to the next generation, and phenomenon of linking and how it affects the assortment of alleles during meiosis (et Smith al.). , 2008). The Introductory Molecular and Cell Biology Assessment (IMCA) (Shi et al., 2010) was also used by us as it included two out of 24 questions on topics examined here. A subset of the learning objectives tested with these questionnaires depends on students using their knowledge of the chromosome structure to answer higher-order questions about genetics and information transfer. Validated ratings like these are valuable tools that allow teachers to gain insight into the concepts their students face, but not necessarily why they struggle with specific topics. In this study, we show that biology students do not think about the molecular and genetic aspects of chromosomes when they describe meiosis or try to make sense of chromosomal behavior. We assume that students do not transfer their knowledge of the chromosome structure when thinking about complex cellular processes such as cell division. Our work suggests that students have difficulty transferring their mental DNA models into the context of chromosome structure. For this work, we describe transfer as the ability to extend what we have learned in a context to new contexts (Bransford and Schwartz, 1999). We do not assess whether students transfer knowledge between academic and daily life or whether they make appropriate use of knowledge across cultural boundaries (Lave, 1988). Instead, we frame our discussion on the transfer of knowledge between two issues in the context of which would most closely match the definition of the Middle Transfer described by Perkins and Salomon (1992). The theory of transfer is relevant for the understanding of the and learning (Mestre, 2005) and was used to explain various phenomena in pedagogical research literature. For example, the work from a multi-part study by Kelly and Jones (2007, 2008) focused on the transfer of knowledge in the context of chemistry students who understand salt dissolution. Students were asked to draw their models of solid sodium chloride (NaCl) and liquid water before seeing an animation about the NaCl resolution. Analysis of the students' drawings and semi-structured interviews showed that all students (18 out of 18) made improvements to their models after viewing the animation, especially in the topics of structure and function. A week later, the same 18 students watched a video demonstrating the precipitation of silver chloride (AgCl) after mixing solutions of NaCl and silver nitrate (AgNO3). Students were asked to draw and explain what they saw during the video demonstration. Although 12 out of 18 (67%) The students said they remembered and thought about the first animation during the second exercise, only two of the 12 correctly drew NaCl as separate ions in their models. None of the students correctly drew the hydration spheres that formed around ions during resolution, although all had previously included this element in their previous model 1 wk. Nine out of 15 students were eventually able to change their models to show the correct separation of Na+ and Cl ions. Although this is an excellent example of lack of transfer, it is an interesting and complex question why the students were unable to make the connection from the first to the second demonstration, and is an interesting and complex question that remains unresolved. In an excellent review of the transfer literature, Barnett and Ceci (2002) point out that there is little agreement in the scientific community on the nature of the transfer, the extent to which it occurs and the nature of its underlying mechanisms. We used a grounded theoretical approach (Martin and Turner, 1986; Strauss and Corbin, 1997; Creswell, 2007) to combine our observations and assessment and interview data collected from different courses and student groups. The use of a grounded theory keeps researchers close to their collected data and not to what they might have previously assumed or wanted (Holstein and Gubrium, 2003). This approach allowed us to identify key characteristics and topics that were repeated in different contexts (introduction by advanced biology courses) and with different students (first year through senior level) that gave rise to a free-flowing hypothesis, rather than data that was that they fit into a prescribed hypothesis. In this sense, emerging coding strategies were used to analyze data sets, so that key categories and ideas could be identified after an initial evaluation. These approaches reinforce our argument that knowledge may be the main cause of student confusion presented here, and our results are not isolated results that depend on course or instructors. We use coded worksheet data, modeling exercises, and student interviews to show that biology students know about chromosome composition and structure, but do not use this knowledge in the context of cell division (mitosis and meiosis) and the transmission of genetic information. All subsequent protocols were approved by the Institutional Review Board, Rochester Institute of Technology, and all research topics were informed of the facts. Pseudonyms are used in this paper to ensure confidentiality. We looked at the phenomenon holistically by examining the mental models of students in a group of students at levels ranging from beginner courses (freshmen) to advanced biology students (upper-level electors). The data was generated by biology students in various courses at a large private institution as follows. Multiple choice questions (MULTIPLE choice questions) from concept inventories and an open answer question were used for classroom assessments (see Table 1). Table 1. Questions to evaluate the understanding of the chromosome structureClass TestedQuestionSourceIntroduction to Biology (freshmen)What is the relationship between DNA and chromosomes in higher organisms? GLAa (Question 16)Introduction to Biology and Molecular Bio (Sophomores)What is the relationship between genes, DNA and chromosomes? GLA (Question 1)Cell Biology (Sophomores)Describe the relationship between chromosomes, DNA and genes. [open response] This PaperCell Biology and Molecular BiologyThe photo below shows a single replicated chromosome (consisting of two sister chromatids) just before mitosis. This chromosome contains... [Number of single- and double-stranded molecules] IMCAb (Question 19)Cell Biology and Molecular BiologyThe replicated chromosome in question 19... [DNA from how many parents?] IMCA (Question 20)Human Genetics (Juniors/Seniors)A man is a carrier for Wilson's disease (Aa) and Rotor Syndrome (Rr). Suppose the genes involved in these two disorders are both on chromosome 13 (a non-sexual chromosome). The following are possible representations of its genotype... Which of them could be right? [Representation of genes A and R on the same chromosome or otherwise; recessive alleles on the same chromosome or otherwise] GCAc (Question 13)Suppose there are two genes on two different chromosomes, one gene called G and the other d.C. A person has the genotype GgDd. Which of the following drawings shows cell by cell in this individual after DNA replication, but before the of the first meiosis? [Representations of alleles on sister chromatides vs. homologous chromosomes] GCA (question 23)In the germline cell below are two pairs of chromosomes on which the two different genes. F and f represent two different alleles (versions or variants) of one gene, and Q and q represent two different alleles of another gene. If this cell divides normally to produce sperm, what are the possible sperm genotypes? [unrepable chromosome representations of unlinked genes] GCA (Question 2)Sue's chromosome #18 couple looks like this: [A and A, unreplicated representation] Bob's chromosome #18 pair looks like this: [A and a, unreplicated] Bob and Sue have a stillborn son with three copies of chromosome 18 which look like this: [A and A and A, unreplicated] In which parent did the chromosome separation problem occur? GCA (Question 20)A number of instruments were used in a number of different classes as described below. In any case, the pre-school pre-school tests were carried out to inform us about the students' knowledge of the subject and the understanding of the students throughout the curriculum. In order to examine the students' previous knowledge of the relationship between DNA, genes and chromosome structure, we asked students questions from GLAI (Bowling et al., 2008) in an introductory course in biology (n = 71) and in a molecular biology course of the middle level (n = 96). The students who completed these exams were either first-year biology graduates or second-year students who had already completed a year of introductory biology. To further support all findings from the MCQ, we asked a randomized subset of second-year cell biology students (n = 46) to explain the relationship between chromosomes and DNA in an open short answer question. To measure students' knowledge of chromosome structure and function, we asked middle class students enrolled in cell biology (n = 71) and molecular biology (n = 96) to answer selected questions in MCQ format from the IMCA (Shi et al., 2010). Since a firm understanding of the chromosome structure and function is central to these two gateway courses, valuable information about student models could be obtained from these populations. In order to research knowledge and ideas about chromosomes and genetic information flow from upscale biology majors, we asked questions from the GCA (Smith et al., 2008) on nine broad learning objectives of genetics for students (n = 24) in a human genetics course. To enroll in this course, students must have completed basic introductory, cellular biology and molecular biology courses. Although it is not required, half of these students had also taken a basic genetics course. A second cohort of students (n = 131) who are The program of cell biology was tested for their conceptual understanding of the meiosis process with an open pre-test before the topic was dealt with in the classroom. These students had already been exposed to meiosis in college and at least once before their bachelor's degree. Have been. Students were given a diagram representing a precursor germ cell with three pairs of unreplicated chromosomes (Figure 1) and were asked to draw the most important steps of meiosis to demonstrate the structure and behavior of the chromosomes during this process. The representation contained three maternal and three paternal chromosomes, represented as three black and three white structures with matching sizes and shapes for each homologous pair. Student drawings were analyzed and encoded with an emerging coding scheme that allowed us to identify common topics within students' data and responses. Figure 1. Diagram from the open test question given to students in two main courses. In the manual, this figure was described as a precursor germ cell with three pairs of chromosomes. Note that unreplicated chromosomes are represented and one of the pairs of chromosomes is acrocentric, while the other two are metacentric. Before receiving meiosis education in the second cohort of cell biology, the students constructed their own models into groups of four to six students during the recitation period (84 students divided into 17 groups; 15 groups were recorded on video). Students were asked to show what they thought were the main features of meiosis and to develop a model that could be used to teach meiosis in a biology class. They were given manipulative materials for their modelling (e.B. pipe cleaners, construction paper, markers, cord, wooden rods and colored beads). The students' models and explanations were captured on video, but the instructors did not attempt to correct errors during this exercise. Elements of the students' models were encoded as those that required an understanding of DNA and chromosome structure (e.B. replication was correctly described in their model) with elements that were not (e.B names of the meiotic phases were part of their model). Each group gave an oral description of their model. These verbal explanations were transcribed and combined into a single document that could be used to determine the frequency of terms used by the students. A corresponding expert document, to be used as a comparison with student descriptions, was produced by combining a review article by the National Academy of Sciences, USA (PNAS) on meiosis (Kleckner, 1996) and a textbook section describing meiosis (Alberts et al., 2002). A bi-directional gap analysis (Schoenfeld and Herrmann, 1982) was carried out to show how terminology differs between experts and students. The use of words has been and expressed as a percentage of the total words in the document. The nonverbal vocalizations of the students (such as uh and um) were removed before the analysis. Similarly, numbers, titles, and quotes have been removed from the experts' version. Common English words that are not relevant to the topic (e.B. which, and, is) were included in the sum but ignored create the top 10 list for each document. Detailed interviews were conducted with five representative students of the introduction to biology to examine their understanding of the chromosome structure after the academic quarter in which they were taught cell division. High school biology students who had completed the cell biology course minimally (and were not part of the group that completed the pre-testing and modeling exercises) were also invited to extensive interviews at the personal invitation of the researchers. Fourteen students were interviewed in pairs using the graph in Figure 1 as a starting point. A further nine students were interviewed individually with paper questions and/or manipulative materials. All student interviews were recorded on video. In assessments of concepts of DNA and chromosome structure, students enrolled in Introduction to Biology (Freshman Course) and Cell Biology and Molecular Biology (typically sophomores) were asked about the relationship between DNA and chromosomes based on validated, published questions from GLAI (Bowling et al., 2008) and IMCA (Shi et al., 2010). The vast majority of students at all levels were able to correctly answer questions about the basic chromosome structure and the relationship between chromosomes and DNA (Figure 2). Figure 2. Biology students show knowledge of DNA and chromosome structure. Introduction to biology (Intro Bio, n = 71), Cell Biology (Cell Bio, n = 46) and Molecular Biology (Mol Bio, n = 96) were asked to correctly identify the relationship between chromosomes and DNA in MCQ format (Intro Bio and Mol Bio) or in open format (Cell Bio). Extensive interviews were conducted with Introduction to Biology students to investigate their understanding of chromosome structure. When asked whether a chromosome should be described or defined, all five respondents stated that chromosomes are made of DNA, although their descriptions were not necessarily complete: Annie: Well, I would probably say that it definitely consists of many parts. It's DNA, proteins are in there, wrap it up to make sure everything is beautiful and tidy in the cell, and essentially a chromosome is almost like a blueprint because it determines what the body is made of, what it will be, and pretty much everything about it – that body or cell in general. Leah: A chromosome is a -- it's uh -- what you get when you condense long strands of DNA into your UH DNA protein complexes. It's what they use—what the cells use for replication and for meiosis. Nate: It's a bunch of crammed DNA, and then usually two of them are tied to the centrome. Although the of the second year, who took the cell biology course, were able to describe the composition of chromosomes in an open question format, made many mistakes regarding the nature of genes. The analysis showed that 96% 96% of 46) students could clearly describe the correct relationship between chromosomes and DNA, but of the 20 students who expanded their responses to the role of genes, half naively indicated that genes encoded for properties, properties, functions or phenotypes, suggesting an unclear understanding of the central dogma. Students most likely learned this definition of a gene based on middle school or high school discussion of classical genetics, not from a molecular perspective. Only 50% of responders correctly wrote that genes were encoded for proteins. While we acknowledge that this is too simplistic a definition of a gene, some genes encode functional RNAs (Pearson, 2006; Gerstein et al., 2007), the link between gene and trait, which requires expression and function of a gene product, seems to be missing from the mental models of students. Although the vast majority of students show that chromosomes consist of DNA (Figure 2), fewer students seem to apply this basic knowledge when they encounter problems related to chromosome structure and information flow (Figure 3). Of the cell biology students tested, 67% knew that two double-stranded DNA molecules contained a replicated chromosome, but only 33% believed that the same chromosomes contained genetic information from just one parent. Figure 3. Cell biology students do not transfer knowledge of chromosome structure into concepts that contain genetic information. IMCA (Shi et al., 2010) was administered to 68 students shortly before the completion of the cell biology course. The percentage of students who answered questions 19 and 20 correctly (top and bottom bar) is displayed. Advanced students entering human genetics also seem to have difficulty applying knowledge of the basic chromosome structure to problems that focus on meiotic cell division, despite the fact that all students enrolled in this course were repeatedly exposed to the principles of meiosis (minimum in high school, introductory biology, cell biology, and molecular biology; almost half had also taken genetics). Figure 4 shows the results of selected questions from the GCA (Smith et al., 2008) that were asked on the first day of teaching. The majority of students were able to correctly identify representations of alleles on a pair of unreplicated chromosomes (71%) and products of normal meiosis in terms of alleles (67%), but few students captured deeper level components of the process. Only 27% of students identified the correct representation of alleles on replicated chromosomes, and 18% were able to identify products from a in the form of alleles. The latter questions examined the superficial elements of chromosomes and meiosis and required the integration of knowledge about heredity and chromosome structure. The highlighted student errors suggest that the typical biology student biology student think about genes or alleles in the context of chromosome behavior. This is clearly problematic for students trying to understand complex cellular processes and genetic mechanisms. Figure 4. Advanced students do not teach knowledge of chromosomal structure when thinking about alleles. The GCA (Smith et al., 2008) was given to students taking a human genetics course (an upper-level elective subject, n = 24). The results of questions 13, 23, 2 and 20 from version 6.22 are displayed. The red-blue show questions paired with concept; dark bars indicate simple recognition questions, and light bars indicate questions that require deeper understanding. A total of 131 cell biology students conducted a pre-test assessment to examine their understanding of meiotic division. Students were given a diagram (Figure 1) marked as a precursor germ cell with 3 pairs of chromosomes and were asked to draw the most important steps of the meiotic division. Student drawings were analyzed and encoded with a newly emerging coding scheme. Only 16% of the students correctly demonstrated the main replication step in their meiosis models (Figure 5). Many students (41%) showed replication, but with a number of errors, such as the fusion of maternal and paternal chromosomes (similar to formation identified by fertilization misunderstanding by Smith, 1991), the addition of additional arms to the acrocentric chromosomes, or end-to-end fusion of acrocentric chromosomes. In fact, 35% of the students did not adhere to the given chromosome model and added or subtracted chromosomes or entire chromosomes to adapt their mental models of this process to the given situation. Figure 5. The vast majority of students did not demonstrate correct replication of chromosomes in the first step of meiosis. In the open question format, the cell biology students (n = 131) were asked to draw the steps of meiosis, starting with the diagram in Figure 1. The representations of chromosome replication were evaluated. The green bar indicates the percentage of students who demonstrated replication correctly. red bars indicate basic errors; and orange bars indicate important omissions. Values do not add to 100% because multiple categories can apply to a single drawing. Before teaching meiosis in class, students of the cell biology course were asked to construct models of meiosis with manipulative materials during their recitation periods. Similar to our observations of student drawings, most of these groups were unable to complete and accurate to develop. Table 2 compares the essential characteristics of each group's physical model. Group work had a positive impact on their final results, but 64% of the groups presenting a reasonable model left out important traits such as parental origin of chromosomes, allelic differences and exceeding. that the The textbook representation uses the size of the drawn chromosomes to indicate which homologous and color represents parental origin. Interestingly, only five groups (33%) Differences between homologous chromosomes (either with different alleles or with different origins) are shown. Many of the groups (seven out of 15) used the color and length of their pipe cleaner chromosomes redundantly; both characteristics seemed to indicate which chromosomes were paired with each other, and the concept of parental origin was completely absent. Two of the groups trying to represent parental origin constructed false hybrid chromosomes in which a sister chromatid came from each parent. Table 2. Characteristics of the physical models of meiosis, the student groups createdaGroupMeaning of sizeMeaning of colorChromosome structurePairing during the Meiose ICrossing overOverall model1No differencesParent OriginHybrid, unreplicatedNone (sister chromatide only)Not shownPoor2Homolog couplesHomologe pairsCorrectHomologous pairsNot shownModerate3Homlogous pairsHomologe pairsCorrectMispairedNot shownModerate4Homlogous pairsCorrectlogous pairsDifferent alleles representedGood5Homologous pairs No differencesCorrectlogous pairs orientation simlines not displayed6Not displayed6No differencesParentoriginbCorrectHomologus pairsVarious alleles shownGood7No differencesHomologist pairsNot displayed8No differencesHomologus pairsNot displayedModerate9No DifferencesHomologus pairsCorrectHomologous pairsChanging the shown segmentsModerate10Homlogous PairsHomologe PairsCorrectHomologous pairsNot shownModerate11Homogue PairsHomologist PairsCorrectHomologous pairsNot shownModerate12Homoologist CouplesParent OriginHybrid, replicatedUnspecificNot displayedNot displayedPoor13No differencesHomologous pairsCorrectHomologous pairsNot shownModerate14Homologus pairscParental originCorrectHomologous pairsChanging segments representedGood15No differencesHomoologist pairsNot shownModerateanalysis of their explanations showed similar omissions of important concepts. While most groups were able to superficially demonstrate the overall picture of meiotic division (a cell with a complete set of paired chromosomes becomes four cells with a copy of each chromosome), the majority did not show a deeper understanding of the molecular mechanisms and consequences that drive the process (Figure 6). For example, only 33% of models contained physical contact with chromosomes, only 21% of pupils mentioned genetic content in their descriptions, and only 14% considered it necessary to indicate the purpose of meiosis. Figure 6. Content analysis of student models of meiosis in the A total of 14 groups of five to six pupils received 30 to 40 min to The meiosis with manipulative materials. Their statements were recorded on video and analyzed for content. Blue bars indicate elements that demonstrate an understanding of the molecular structure/behavior of chromosomes; orange bars indicate elements that are not based on a solid understanding of the relationship between DNA and chromosomes. The students did not show that the homologous DNA sequence is what drives the mating of homologous chromosomes during meiosis. Only five out of 15 groups included the crossing in their models, and from this subset, only one student indicated that a crossing was necessary for the meiotic process. The other students described the crossing as a side effect. In this context, the term crossing over refers to synapse or physical association of replicated chromosomes during meiosis. To prevent the research team from influencing the thinking student, the team members asked the students: Is crossing necessary for meiosis?, only after the students had introduced the term crossing (no student used the terms synapsis or recombination) or when manipulating their pipe cleaner chromosomes demonstrated a physical touch of chromosome arms or the switching of alleles. Since the physical interaction between replicated homologous chromosomes is essential for proper chromosome alignment and segregation during meiosis, the description of the process as a side effect suggests that students do not consider a chromosome structure when describing chromosome behavior. Each of the groups participating in the study was given enough time to explain and demonstrate their model of meiosis. Transcripts have been produced from the 15 explanations recorded on video; these 2869 words, and word counts were performed to determine the terms most commonly used by biology students. As shown in Figure 7, some of the most commonly used terms were cell, chromosomes, line-up, two and apart. To compare the student's thinking with the thinking expert, we have the text from a PNAS review article titled Meiosis: How could it work? Combined. (Kleckner, 1996) and a passage on meiosis from molecular Biology of the Cell, 4th edition (Alberts et al., 2002), except all in-text quotes, titles, author names and figure legends. As shown in Figure 7, the most commonly used terms used by experts were chromosome(s), homologic/interhomologist, interaction(s), sister/intersister and recombination. A bi-directional gap analysis (Schoenfeld and Herrmann, 1982) was carried out to provide the top 10 technical terms with the top 10 terms. that students use to describe the meiotic process. Figure 7. Gap analysis of terminology used by students and experts to describe meiosis. Transcripts (with 2869 words) from student explanations of meiosis (n = 15 groups) and passages from a PNAS review article and a textbook passage (10,926 words combined) were analyzed in order to Terms commonly used by students and experts (by percentage) when describing diemeiosis. (A) The top 10 terms used by experts and (B) the top 10 terms used by students. Terms used in either group with 0.05% or less are marked with an asterisk. Interaction was used 113 times (1.03%) experts and zero times from students. The same was observed in the words homologue and recombination, which were 143 (1.31%) used. and 82 (0.75%) experts. Students, on the other hand, focused more on the words cell and nucleus than experts, using terms such as line-up and pull-apart to describe chromosome behavior. From these two analyses, we deduce that the typical student is thinking about the process of meiosis in relation to the overall picture of the cell and the chromosome. In contrast, the process of meiosis for the expert can be explained by homology, interactions and recombinations, all of which are driven by the molecular structure of the chromosomes. Detailed interviews with biology students complement the data from the above classroom assessments. In interviews focusing on the process of meiosis, many students used the term DNA and showed sophisticated knowledge of chromosomes and other relevant concepts, but were then unable to explain homologous mating or molecular interactions of chromosomes. In most interviews, students found the start chart (Figure 1) confusing. The drawing was specially designed to differ from the typical textbook diagram in several ways to see if the students could apply the knowledge learned in one format to a slightly different situation: chromosomes were not replicated, there were an odd number of pairs of chromosomes, and a pair of chromosomes was acrocentric. Although some students may not have previously been exposed to an image of an acrocentric chromosome, it served as an important opportunity for students to demonstrate knowledge transfer using chromosomal knowledge in a new context. In the following passage, two students mistakenly solve the

problem of two unreplicated acrocentric chromosomes by pairing them end-to-end: Interviewer: It seemed like... these chromosomes [indicating the acrocentric pair] confused you a little. Can you talk about it a little bit? Brianna: Since it didn't have both [arms] on both sides, I was a little confused about how it would be in the next phase – how it would split and cross. Interviewer: Have you ever seen a chromosome that looks like this? Brianna: I probably did, but I I don't. Alexandra: I think we have it in the... are they called karyotypes? Like the pictures where they can see that oh, 21 has like three, and that's like... Trisomy.... But usually the diagrams in the book have like the beautiful ones like this [displays metacentric chromosome], like oh, that's like they are splitting. So I have seen like the different form chromosomes in real life, but the diagrams are always like the beautiful perfect, full chromosomes. [Interviewer repeats that the acrocentric chromosomes were confusing because they didn't look like the book and received strong confirmation from both. Later in the interview, Brianna admits to being still confused about the acrocentric chromosome:]Brianna: It's not the book orientation. In a separate interview (also using Figure 1 as a starting point), Matt and Alyssa found the two acrocentric chromosomes confusing and solved the problem by pairing the two acrocentric chromosomes in their model (without replicating), so that their cell contained four replicated chromosomes and a hybrid chromosome consisting of a maternal and paternal chromosome shortly before meiosis. The students puzzled about the subject of five chromosomes in the passage below: Interviewer: Well, so let's start talking about what you did. The first thing you had to do here was to find out what this image meant. So can you tell me what this image meant to you and whether there was anything confusing about it? Alyssa: Well, it says 3 pairs of chromosomes, that would mean six, but if you pair them together, there are only... Matt: ThreeAlyssa: I mean, that means six separate chromatides and there are five. Interviewer: There are five? Matt: There are these two, these two, and these two. Interviewer: So do you see these as different from these [metacentric chromosomes]? Alyssa: YeahInterviewer: Have you ever seen a chromosome look like this? Matt: Not reallyAlyssa: Not really interviewer: That was kind of confusing for you? Matt: YeahInterviewer: Okay. What did you decide to do in the end? Alyssa: We just paired it as one. Matt: Yes, we made it as a chromosome. Because experts have a clear conceptual model of the basic chromosome structure, they do not see textbook drawings and diagrams in the same way as students, and cannot even predict what interpretations students will make when viewing the same image (Benson, 1997). In the example above, students realize that they have been exposed to different representations of chromosomes, but they do not have the opportunity to move between them. Any difference between the representations can lead to confusion for the beginner, especially if he or she does not transfer any previous knowledge of chromosomes to this new situation. For example, elements that are considered to be foreign details (such as the position of a centrifugal bucket) for an expert can be used to create a roadblock become the beginner. Students often showed poor cognitive sensitivity to chromosomes or DNA as molecules. Each of the students in this part of the study had completed at least a year of chemistry, so they had probably learned something about molecular behavior. In In biological context, students do not understand that matter is subject to different types of forces and experiences different phenomena on a molecular or atomic scale as macroscopic objects or whole organisms do. In the following example, Trisha and Kari drew homologous chromosomes (unreplicated) that touched on the focal points: Interviewer: Do you think they are touching in a place other than the centrosome[Pause]Kari: Hm. Maybe they touch, but they are not, I mean, connected. Trisha: yes, because chromosomes like DNA are super-super densely packaged, so when it touches, it's like, I don't know, they don't affect each other by touching. It's not that you can rub some of the DNA or something magically. In several interviews, the students were asked how homologous chromosomes find their partners. Everyone was surprised at first and hesitant before responding. You had obviously never been asked to think about this fundamental question: Interviewer: What do you think allows them to find themselves? How do homologous chromosomes come together? [Pause] Matt: Pairing call? Just kidding... Probably like a hydrophilic attraction or something like that. Something like an electronegative attraction. Interviewer: How would that be specific to mating? Alyssa: Well, they cross, so I assume they would try to find chromosomes that best fit what they have on each other – like the kind of similar genes they have on them. [Matt and Alyssa agree that crossing involves physical contact between chromosomes and chemical bonds, but when you ask them if this is important for the mating process, they say no.] Matt: That's a side effect. James offered a creative solution to the problem of homologous mating in the following passage: James: My guess is that there would be some kind of chaperone protein that interacts with similar chromosomes. But I don't know the specifics of it. Interviewer: So you suspect that there may only be specific proteins for each pair of chromosomes so that the homologues can find each other? James: I don't know if we talked about it, but I think that would be the only way it could happen. All of the above passages are representative of typical student responses. These are not special cases. We have observed time and again that students do not think about the molecular properties of DNA when asked about chromosomal behavior. As in the classical definition of transfer, we argue that the typical biology student knows about chromosomes and chromosome structure in a context, but does not know the knowledge correctly in another Can. Through coded worksheet data, formative assessments, modeling exercises, and student interviews, we have shown that students understand the relationship between chromosomes and DNA, the structure of a and can identify the products of the meiosis (specialized cell department) in relation to alleles. However, the structure of a chromosome is far less reconciled with the structure of DNA, and even fewer students use this knowledge when thinking about genetic information contained in chromosomes or about the flow of information (central dogma). While the students' misunderstanding of central dogmas has been described by other researchers (Lewis and Kattmann, 2004), we suggest interpreting this observation in a broader context. Students do not understand complex processes, not because they do not understand the underlying bits of information, but because they lack critical connections that bind the molecular structure of chromosomes to the central dogma. This also suggests that future work should focus not only on the limits of conceptual understanding, but also on the applicability of known concepts to unknown contexts – the definition of transfer. We believe that biology students do not transfer their knowledge of DNA between different levels of representation: images of entire chromosomes (either photographs or diagrams of condensed chromosomes in cell division), submicroscopic images (e..B DNA sequence or chemical structure) or symbolic images (e.B. a diagram of a gene represented by boxes for promoter and coding areas). This is a similar framework to Johnstone's triangle in chemistry, in which students struggle to move between macroscopic (e.B. salt crystals), submicroscopic (e.B. a chemical structural diagram) and symbolic (e.B. a chemical equation) representations of the same phenomenon (Johnstone and Mahmoud, 1980). In our study, very few students demonstrated the essential replication step correctly when asked to draw the most important steps of meiosis when starting with unreplicated chromosomes. Many students made mistakes when they tried to demonstrate replication (e.B. adding additional arms to the acrocentric chromosomes instead of proper chromosome replication) or not included any replication step at all. We suggest the following explanation: When students are presented with a representation of a chromosome (as shown in Figure 1), they work with only one mental model (something similar to a macroscopic stick) to solve the problem. Most students do not think of chromosomes at the molecular level (DNA sequence) when they are represented with a representation of an entire chromosome. If they did, they would probably be much less likely to forget to include a DNA replication step or to include illogical such as .B, the merging of two unreplicated chromosomes, adding additional arms on acrocentric chromosomes, or simply adding/deleting chromosomes to produce an even number of chromosomes after the second meiotic division. The students we tested seemed to rely on surface features of chromosomal representations, similar to those described by Chi and colleagues (1981), (1981), Strategies used by physics students (beginners) and advanced physics students (experts) to categorize various physics problems were investigated. Beginners relied on surface features and structures found within the problem, such as the presence of pulleys, inclined planes, ramps and springs, while experts used laws of physics, such as energy saving, to determine how the problem should be addressed. Experts are thus able to deal with minor changes in representation because they rely on the abstract principles presented in the problems. Experts and newcomers also deal differently with chemical representations. For example, experts (professional chemists) and beginners (chemistry students) constructed different categories when presented with 14 maps containing either a graph, an image, a chemical equation, or a link to a computer animation on various chemical phenomena (Kozma and Russell, 1997). Beginners tended to combine representations of the same media type (equations), while experts focused more on conceptual thinking in their sorting tasks. Typical biology students do not think of DNA when presented with a macroscopic representation of a chromosome; we believe that they only see surface features (stick-like chromosome models), not molecules, and this prevents them from transferring knowledge of basic chromosome structure to scenarios that involve replication and division. Although the phenomenon of transfer from outside biology has been studied most thoroughly (e.B. Perkins and Salomon, 1988; Mestre, 2002; Schwartz et al., 2011), can and should inform biology educators in their own classroom design. Schwartz and Bransford (1998). described an increased transfer of inclination and knowledge among students who first created diagrams to describe data sets from psychology experiments, compared to peers who summarized a chapter on the same experiments. In another case, students who invented a mathematical formula before class showed an increased knowledge transfer compared to students who were previously simply told the formula (Schwartz and Martin, 2004). One way to increase the transfer of knowledge is to prime or prepare the students by allowing them to construct their own models from which they invent generalizations that are applied in other contexts. Our work implies that teaching should focus as much on the transfer of concepts as on mastery of the concepts themselves. The has begun to reflect the development of physics-educational research by moving from misunderstandings to more fluid theories involving the transfer and activation of resources. For example, a pedagogy in dencontrast with contrast cases (Schwartz et al., 2011) could be implemented, in which the students could have several DNA images (in the macroscopic, molecular and and at the same time asked to create a model or description of the DNA to which all representations would apply. Instructors could make a conscious effort to focus on the relationship between DNA and chromosomes in as many contexts as possible. For example, if students are given genetic problems with the concentration of alleles and the transfer of genetic material, the instructors should ask students to define an allele at the molecular level. If students see a typical textbook image of crossing over during Meiosis I, the instructor should examine their understanding of chromosome behavior (e.B. How do homologous chromosomes align? What does the term homolog mean?) to help students gain basic knowledge about chromosome and DNA structure when thinking about complex cellular processes. In previous work, we have shown how a constructivist activity can be applied in a biological environment to increase the knowledge transfer of key points in meiosis. A key feature of this work was that biology students were first primed for learning by creating their own models of meiosis using manipulative materials (Wright and Newman, 2011). In the following activity, the instructors examined the students about the chromosome structure at the molecular level to help them establish connections between structure and behavior. In the work presented here, we deepened the conceptual models and understanding of the molecular nature and behavior of chromosomes by examining the elements and terminology used or omitted in their meiosis models (Figures 6 and 7). An interesting finding between the two analyses was that only 19% of each student drew correct representations of chromosomes that go through the process of meiosis in a preactivity assessment (Wright and Newman, 2011), while 85% of the group models analyzed in this work were at least moderately correct (Table 2). It is well documented in the literature that peer discussion improves performance in conceptual tasks (e.B. Smith et al., 2009), so that future activities to improve the transfer should require a certain amount of group discussion. Detailed interviews with a number of students confirmed many of our results. An image of an acrocentric chromosome presented the students with a major problem because, the students explained, it did not look like something they were used to in a textbook figure. This image has been specially selected to evaluate the transferability. The students admitted to being unfamiliar with this type of presentation and were able to look beyond the surface as an expert would do, so they could not understand the image. In other words, it did not activate any prior knowledge about chromosome or DNA structure. When analyzing student drawings of meiosis, a significant percentage were found to have two acrocentric chromosomes (end-to-end) or even an alternative number of chromosomes in their drawings because they could not solve the scenario. These manipulations can be compared to the phenomenon of absurdism observed when physics students presented a difficult problem with the relativity of simultaneity (a challenging concept for the typical student). In these situations, students often gave up logic or tried to solve a problem or paradox using scientific mechansime/properties that do not exist (Scherr, 2007). Similarly, we know that chromosomes do not routinely merge, and unreplicated maternal and paternal chromosomes do not mate into hybrid chromosomes, but these explanations were offered several times by students when their understanding was questioned. Although students know DNA and chromosome make-up, they struggle to think about mechanisms (e.B. How do the homologous chromosomes find their partners?). Students did not believe in using knowledge they had learned in other contexts, such as .B base pairing of DNA, to solve the problem. In all the student explanations we analyzed (during the Meiose modeling exercise and extensive interviews), there was only one case of a student who correctly demonstrated and explained the importance of crossing (synapsis or physical linkage of chromosomes) with the process of meiosis. Most students had no idea how homologous pairs of replicated chromosomes were aligned and showed no understanding of the molecular nature of chromosome behavior. We also found that terms such as interaction and recombination were often used by experts (Figure 7), but not by students who instead suggested mechanisms that did not include the structure of DNA. Their chromosome models seemed to be more appropriate to proteins (e.B. hydrophilic, electrostatic) or macromolecular objects (e..B. touching them but not interacting) than the simple base pairing that the DNA structure suggests. Enabling appropriate resources is essential when a new problem occurs. Resources are not necessarily false or misleading, but they can be applied inappropriately to a particular problem, and experts rely on resources other than beginners in the same context (reviewed by Hammer, 2000). For example, when asked how chromosomes mate, an expert can rely on resources based on molecular interactions, while students are more likely to use knowledge of macroscopic objects, such as.B puzzle pieces that fit together. Future work will focus on identifying and testing elements in representations that are Help students think about the underlying structure of chromosomes or activate appropriate cognitive resources that would allow them to use their knowledge when thinking about a complex cellular process. FOOTNOTESWe thank D. Carter, A. Hudson and P. Shipman for helping with collecting Valuation data. We would also like to thank M. Osier and R. Rothman for their insights into the teaching of genetics to students. Special thanks to T. Kim, S. Franklin and N. Pelaez for the helpful conversations. REFERENCES Alberts B, Johnson A, Lewis J, Raff M, Roberts K, Walter P (2002). Molecular Biology of the Cell, 4. New York: Garland Science, chap. Google Scholar Bahar M, Johnstone AH, Hansell MH (1999). Resurgent of learning difficulties in biology. J Biol Educ 33, 84. Google Scholar Barnett SM, Ceci SJ (2002). When and where do we apply what we learn? A taxonomy for far transfer. Psychol Bull 128, 612-637. 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