โมเดลอย่างง่ายและราคาไม่แพงสำหรับใช้ในการจัดการเรียนรู้ เรื่องการแบ่งเซลล์และพันธุศาสตร์ของเซลล์

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รับบทความ: 20 เมษายน 2557 ยอมรับตีพิมพ์: 2 มิถุนายน 2557

บทคัดย่อ

ความเข้าใจเกี่ยวกับพฤติกรรมของโครโมโซมในระหว่างการแบ่งเซลล์แบบไมโทซีสและไมโอซีส เป็นสิ่งจำเป็นสำหรับการทำความเข้าใจเกี่ยวกับการถ่ายทอดลักษณะทางพันธุกรรม แต่นักเรียนจำนวนไม่น้อยพบว่ากระบวนการนี้เป็นเรื่องยากที่จะทำความเข้าใจในสภาพการจัดการเรียนรู้ในห้องเรียน ผู้เขียนได้นำเสนอโมเดลโครโมโซมแบบใหม่ที่สามารถนำไปใช้เป็นสื่อการสอน และช่วยให้นักเรียนเข้าใจกระบวนการแบ่งเซลล์แบบไมโทซีสและไมโอซีสได้ดียิ่งขึ้น โดยเฉพาะอย่างยิ่งกระบวนการครอสซิ่งโอเวอร์ที่เกิดขึ้นระหว่างการแบ่งเซลล์แบบไมโอซีส นอกจากนั้นโมเดลนี้ยังสามารถนำไปใช้เป็นสื่อการสอนในเรื่องอื่น ๆ ที่เกี่ยวกับพันธุศาสตร์ของเซลล์ได้อีกด้วย เช่น ชนิดของโครโมโซม การแยกกันของโครมาติด โครโมโซมคู่เหมือน แคริโอไทป์ พลอยดี วัสดุที่จำเป็นสำหรับใช้ในการสร้างโมเดลนี้หาซื้อได้ง่ายตามท้องตลาดและราคาไม่แพง ด้วยเหตุนี้ โมเดลโครโมโซมนี้จึงง่ายต่อการใช้งานและราคาถูกเหมาะกับผู้ใช้ทุกระดับ

คำสำคัญ: โมเดลโครโมโซม การแบ่งเซลล์ ไมโทซีส ไมโอซีส พันธุศาสตร์

A Simple and Inexpensive Model for Use in Learning Cell Division and Cytogenetics

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Abstract

The comprehension of chromosome behaviors during mitosis and meiosis of cell division is essential for understanding genetic transmission; however, students often find this process difficult to grasp in classroom setting. The present study purposes a new chromosome model that can be used as a learning tool to help students understand these processes, particularly the process of crossing over in meiosis. In addition, it can be used to learn any other aspects in cytogenetics, for example, chromosome type, chromatid segregation, homologous chromosome, karyotype and ploidy. The materials needed are easy to obtain and not expensive. Therefore, it is a simple and low-cost model that is suitable for all users' levels.

Keywords: Chromosome model, Cell division, Mitosis, Meiosis, Genetics

Introduction

Models are useful in classroom setting since they allow the students to easily examine what are difficult to learn exclusively from books. In the past, various conceptual models have been extensively used in the field of chemistry. Such models are also important tools in the biological sciences, where they can enhance students' understanding and problem solving ability (Chinnici et al., 2006).

For all biology instructors, dealing with students misconceptions of cell division may seen hopeless at times even after using visual models. Confusing ploidy with chromosome structure is recognized as a common misconception of mitosis and meiosis (Kindfield, 1991; Ozcan et al., 2012). Clark and Mathis (2000) point out that, essentially, "students struggle to distinguish between chromatids, chromosomes and homologous pairs of chromosomes." Smith (1991) asks a frustrating question that most instructors can identify with: "If students have studied cell division repeatedly, why do they continue to difficulties with it?" Although students errors in cell division are built around the three key events of cell division, i.e., chromosome doubling, paring, and separating (Smith, 1991), no panacea exists to relieve biology instructors of the recurrent learning patterns that seem to afflict students year after year. Therefore, each type of misconception must be treated separately to effectively resolve students misunderstanding. Taking advantage of models carefully designed to address to achieve this goal.

Today, many biology instructors use visual models to help students understand abstract concepts such as cell division. Available of cell division chromosome model now comes in many varieties. Simple wooden clothes pegs can be used to learn cell division and genetic (Coleman, 1986). Instructors may also choose to make chromosome represented by pin boards (Gow and Nicholl, 1988), hand models (Mickle, 1990; Ward, 1988), pizza chromosomes (Rindos and Atkinson, 1990), wooden blocks (Pashley, 1994), pieces of ribbon (Levy and Benner, 1995), string and paper game (Stencel, 1995), yarn and chenille stems (Clark and Mathis, 2000), and paper labeled of dragon chromosomes (Harrell, 2001). Some instructors used socks to represent chromosomes or ploidy during cell division (Chinnici et al., 2006; Oakley, 1994; Stavroulakis, 2005). Alternatively, Luo (2012) creates a double-spring model to learn chromosome movement during mitosis and meiosis. Although these models are wildly used for many years, such models remain ineffective in facilitating learning and understanding of cell division in some aspects.

The more creative and effective innovations today might be chromosome simulation using “chromosome bead or pop-bead or bio-bead”. It is simple, handle, and available in some countries, e.g., United States and Canada. However, this model could not be found in Thailand, and ordering for these materials may take a few weeks or a month. More importantly, it is expensive for international ordering and shipping which can cost from 3,000 to more than 8,000 Thai baht. Therefore, the aim of this study was to develop a simple, inexpensive chromosome model that is practical for use in a high school science class and also an undergraduate biology class and that could serve as the basis for students’ investigation of: (1) structure and type of chromosome, or (2) chromosome’s behaviors during mitosis and meiosis.

Materials used to construct the model

A pack of plastic chain rings which is easily found in toy stores (Figure 1A). Each pack is sold for 5 Thai baht and contains 100 rings per pack.

A plastic or magnetic centromere can be found in toy stores or can be ordered from the internet (Figure 1B). A plastic centromere is sold for 0.05 Thai baht on the other hand a magnetic centromere is sold for 29.75 Thai baht.

Figure 1C showed the construction of chromosome by using the materials provided.

Learning with the chromosome model

What can be learnt by the new chromosome model?

1. Chromosome type and separation

There are four types of chromosome according to the position of centromere. When the centromere is situated at the tip so that each chromatid has only one arm, this is called telocentric chromosome. Such a chromosome attains the shape of 'I' during anaphase (Figure 2A). Acrocentric chromosome

Figure 1 Materials for constructing a new model of chromosome; (A) plastic chain rings, (B) plastic and magnetic centromere, and (C) chromosome models assembly from plastic chain ring and plastic or magnetic centromere

has a chromosome attains the shape of 'J' during anaphase (Figure 2B). Sub-metacentric chromosome has a centromere located slightly away from the center and hence the two arms are unequal. Such a chromosome attains the shape of 'L' during anaphase (Figure 2C). Finally, when the centromere is exactly in the center and the two arms are of the same length, this is called a metacentric chromosome. Such a chromosome assumes the shape of 'V' during anaphase (Figure 2D) (Reech et al., 2011).

2. Homologous chromosome

Homologous chromosomes are chromosomes containing the same genes order along their chromosomal arms (Picture 3). One homologous chromosome is inherited from the organism's mother; the other is inherited from the organism's father. There are two main properties of homologous chromosomes, the length of chromosomal arms, and the location of the centromere. Both of these properties are the main factors for creating structural homology between chromosomes. Therefore, when two chromosomes of the exact structure exist, they are able to pair together to form homologous chromosomes (Reech et al., 2011).

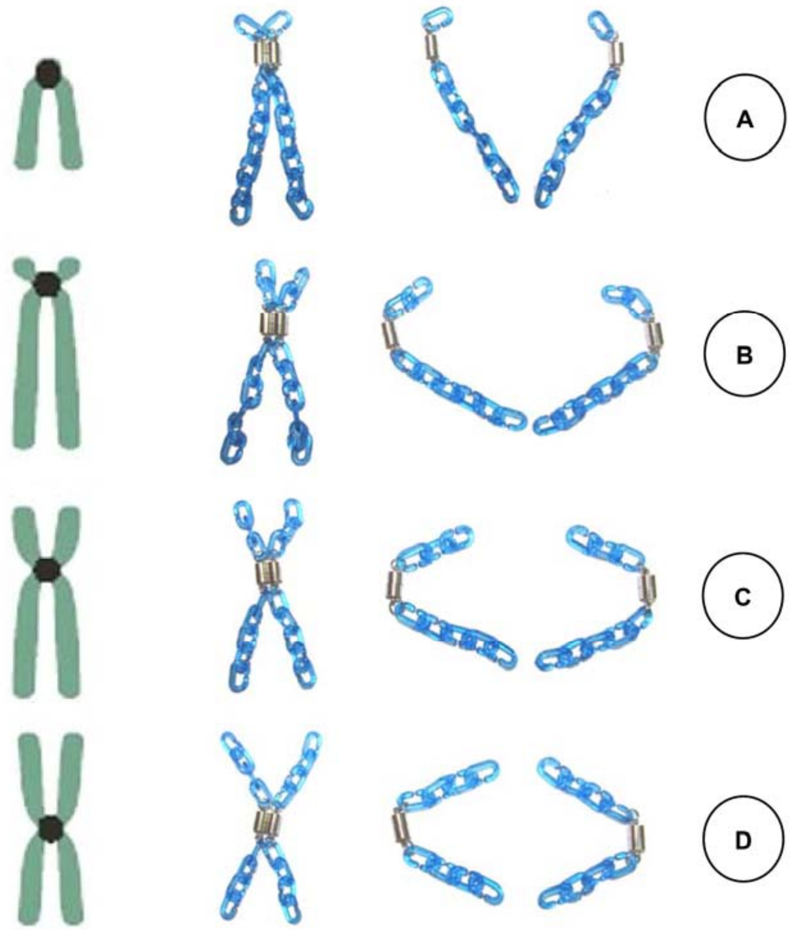

Figure 2 Types of chromosome based on the position of centromere; (A) Telocentric chromosome, (B) Acrocentric chromosome, (C) Sub-metacentric chromosome, and (D) Metacentric chromosome

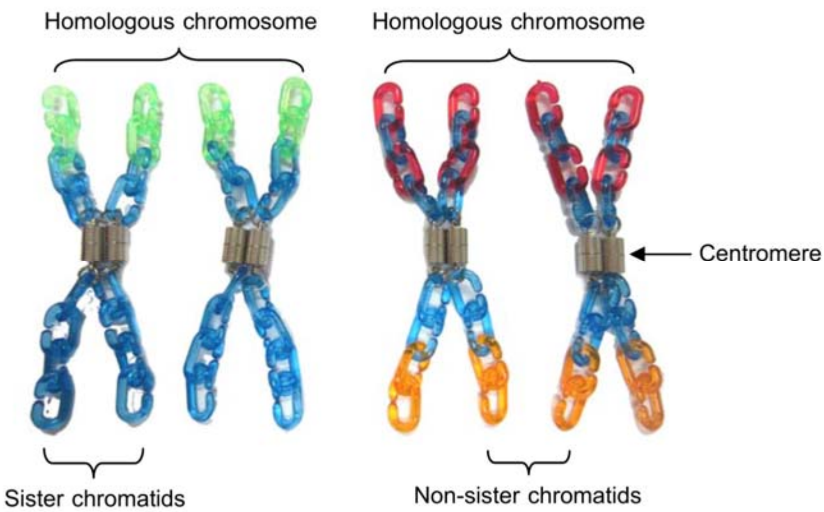

Figure 3 Homologous chromosome showing centromere, sister chromatids and non-sister chromatids

3. Chromosome behaviors during mitosis

Cell division is a process with sequence of steps that enables organisms to gain the growth and reproduction. Genetic materials are replicated in parent cells and distributed equally into the two daughter cells. Cells undergo a period of growth called interphase before entering mitosis. During the interphase, the genetic materials replicate, and the organelles prepare for division. In the process of mitosis, the parent's cell genome is transferred into the two daughter cells. The daughter cells are similar to each other and to their parent cells. The cell's genome is composed of chromosomes that are complexes of tightly coiled DNA that contain the genetic material which is vital for the proper functioning of the cell (Reech et al., 2011).

The process of mitosis, generally called mitotic nuclear division, is conventionally broken down into four stages. In prophase, the chromatin fibers condense into discrete chromosomes and the nuclear envelope fragments (Figure 4A). During metaphase, the chromosomes align themselves at the metaphase plate (Figure 4B). Then, microtubules pull apart the sister chromatids of each chromosome. This stage is called anaphase (Figure 4C). In telophase, the daughter chromosomes are pulled towards opposite ends. The separate daughter chromosomes relax and nuclear membrane is formed around them (Figure 4D). In animal cells, the area of cell membrane pinches inwards, to form the two daughter cells, the imaginary line is called the cleavage furrow which separates the developing nuclei. In plant cells, the new dividing cell wall is constructed in between the daughter cells. The parent cell will thus split in half and give rise to two daughter cells (Reech et al., 2011).

4. Chromosome behaviors during meiosis

During meiosis I, the chromatin condenses into chromosomes, which are long threads. Two homologous chromosomes come together and locate side by side. Pairing takes place along their entire length. The two homologous chromosomes split longitudinally. The homologous pairs are connected at some points called chiasmata (*sing.* chiasma) followed by the exchange of chromatin material (Figure 5A). Then, the four chromatids (in two pairs) are attached to spindle fibers by two centromeres and locate in the middle of the cell (Figure 5B). The two pairs are then separated and moved towards the opposite poles of the spindle fiber (Figure 5C). The chromatid pairs (chromosomes) form a compact group at each pole. The two daughter nuclei thus formed contain haploid or (n) chromosomes (Figure 5D). The two daughter cells then undergo meiosis II, which is actually mitosis (Figure 6). Meiosis is thus an equational division resulting in four daughter cells with half the number of chromosomes, haploid (Reech et al., 2011).

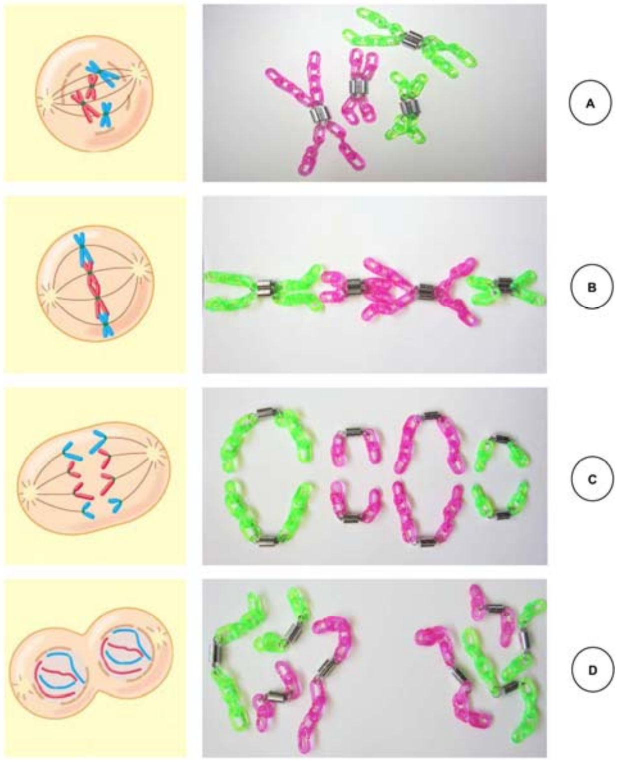

Figure 4 The stages of mitosis: (A) Prophase, (B) Metaphase (C) Anaphase, (D) Telophase

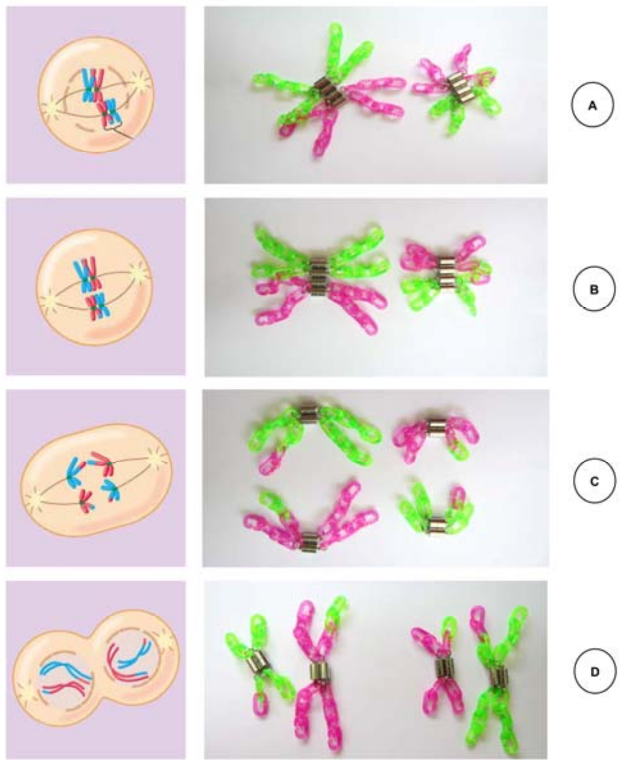

Figure 5 The stages of meiosis I: (A) Prophase I, (B) Metaphase I, (C) Anaphase I, (D) Telophase I

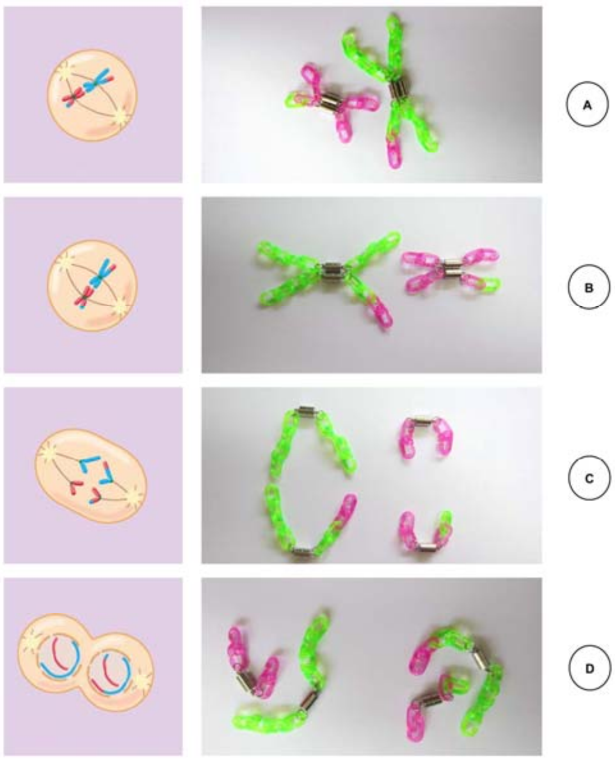

Figure 6 The stages of meiosis II: (A) Prophase II, (B) Metaphase II, (C) Anaphase II, (D) Telophase II

Comparing the chromosome chain model with the others?

As described previously, available chromosome models now come in many varieties. Comparing the chromosome chain model with the others is shown in Table 1. Among these, some are good to demonstrate chromosome movement but could not show the process of crossing over, for example, a double-spring model (Figure 7A). Some are too big; for example, a model of chromosome socks (Figure 7B). Some are not flexible liked wooden blocks and paper labeled of dragon chromosomes (Figure 7C). Even one of them is an effective tool such as "chromosome bead or pop-bead or bio-bead" (Figure 7D) but it could not be found in Thailand and ordered for these materials may takes a few weeks or a month. More importantly, it is expensive for international ordering and shipping which can cost from 3,000 to more than 8,000 Thai baht. The model presented in this article could solve these problems (Figure 7E).

Table 1 Compare the chromosome chain model with the others

Model	Strength	Weakness
A double-spring model	Be able to show movement of spindle fibers	Expensive; not be able to demonstrate crossing over; difficult to find materials
A chromosome sock	Suitable for teaching mitosis, homologous chromosome, karyotype, and ploidy	Expensive; not be able to demonstrate crossing over; difficult to find good materials
A dragon chromosome	Inexpensive; available in Thailand; suitable for teaching genetic inheritance	Not suitable for teaching mitosis and meiosis (not flexible and not be able to demonstrate crossing over), chromosome type, chromatid segregation, homologous chromosome, karyotype and ploidy
A chromosome bead	Suitable for teaching mitosis and meiosis (flexible and be able to demonstrate crossing over), chromosome type, chromatid segregation, homologous chromosome, karyotype, and ploidy	Expensive; not available in Thailand
A chromosome chain	Inexpensive; available in Thailand; suitable for teaching mitosis and meiosis (flexible and be able to demonstrate crossing over), chromosome type, chromatid segregation, homologous chromosome, and karyotype	–

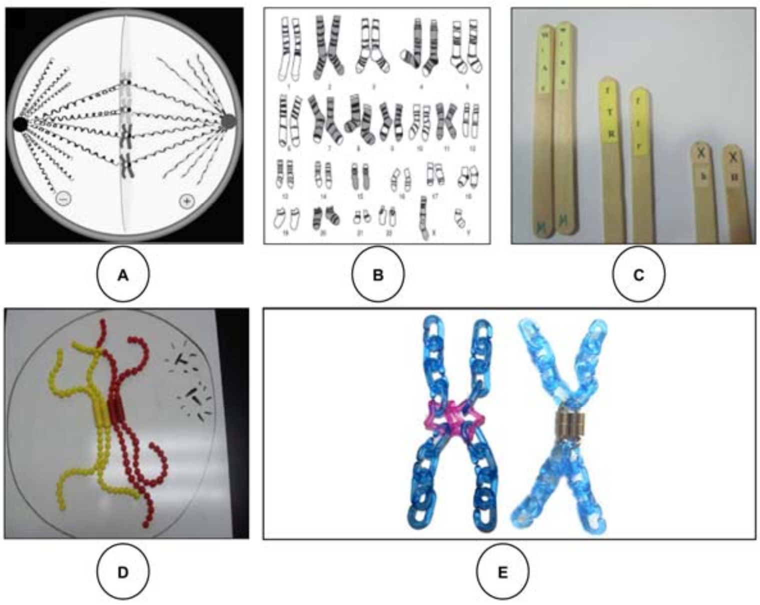

Figure 7 Some available chromosome models in classroom: (A) a double-spring model, (B) a model of chromosome socks, (C) a dragon chromosomes, (D) a chromosome bead or pop-bead or bio-bead, and (E) chromosome chain model

Conclusion

The new chromosome model made from plastic chain ring can be used as a teaching tool to help students understand chromosome behaviors during mitosis and meiosis, especially the process of crossing over in meiosis. It can be used to teach any other aspects in cytogenetics, for example, chromosome type, chromatid segregation, and homologous chromosome. This is a simple and low-cost model that is suitable for all level of users. In case of low financial support, a plastic centromere was recommended for use instead of using a magnetic centromere. In addition, the teachers might apply this model for students to investigate about karyotype, ploidy and any other aspects in cytogenetics.

Acknowledgments

The author would like to thank Miss Yupin Ployyod, a master student in Science Education Program, Faculty of Science, Ubon Ratchathani University, for her participation and support.

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