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DETERMINING THE COGNITIVE STRUCTURES AND MISCONCEPTIONS ABOUT CHROMOSOME AND HOMOLOGOUS CHROMOSOME CONCEPTS IN HIGH SCHOOL STUDENTS: DRAWING-WRITING TECHNIQUE

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Abstract:
This study aims to determine the cognitive structures related to the chromosome and homologous chromosomes as well as the misconceptions of high school students. 140 10th-grade high school students participated in the study. Data were collected using the drawing-writing technique. The students were asked to draw the chromosome and homologous chromosomes separately, to identify their elements, and to write an explanatory sentence about these concepts. The drawings and explanations were analyzed separately and the students' cognitive structures and misconceptions were investigated. The analyses revealed students have misconceptions about the chromosome and homologous chromosomes. The study results emphasize that effectively teaching the concept of chromosome and homologous chromosomes; the basic concept of the cell cycle, is fundamental for further science studies.

Keywords: chromosome, homologous chromosome, drawing-writing technique, misconception

1. Introduction

As technology advances, failures in education systems are emerging as an important problem to overcome. Failures include students who are less successful in science courses such as biology, physics and chemistry, where abstract concepts are intensely used. The deficiencies observed in students have been identified under the labels of misconceptions, conceptual change and cognitive structures in educational studies. Tekkaya, Çapa and Yılmaz (2000) indicated that misconceptions are students' alternatives to ideas accepted to be scientific and many studies on biology education underlined that students have misconceptions. Literature review revealed that a large variety of measurement instruments is used to determine students' misconceptions. For

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instance, while Temelli (2006) used 17 multiple-choice questions to determine second- and third-year high school students' misconceptions about genetics, Harman (2014) used the prediction-observation-explanation technique to determine 89 science teachers' misconceptions about substance passage through cell membranes. Moreover, concept maps which are used as a teaching method and an alternative assessment instrument are widely used to determine misconceptions (Novak & Gowin, 1984). The concept of chromosome and homologous chromosomes is fundamental in understanding cell division and reproduction as well as genetics. A structural and functionally inadequate understanding of these concepts impedes understanding of later topics such as cell division and development. The concepts of chromosomes ultimately substantiate the concept of biodiversity. These important, abstract concepts were investigated in various studies using different measurement tools and it was determined that students have misconceptions about these concepts. Several studies conducted with students from different academic levels demonstrated that they have misconceptions about genetics concepts (Tekkaya, Çapa, & Yılmaz, 2000; Stewart, Hafner, & Dala, 1990; Fisher, 1985). Emre and Bahşi (2006) investigated misconceptions about cell division with 76 preservice science teachers. Their results highlighted that 47.4% of the students made an incorrect definition of homologous chromosomes and 25% of the students have misconceptions about the definition of chromosomes. Temelli (2006) posed the question, "Where are genes in the body?" to students using multiple-choice answers. Two-thirds of the students responded that genes are in the chromosomes, while one-third indicated that genes are in human or reproductive cells. It was also found that only 35.3% of the students comprehended the relationship between DNA and chromosomes while the other students did not understand this relationship. Temelli (2006) illustrated that one-third of the students correctly identified the tasks of chromosomes, however, the remaining students did not know the correct response. Can and Akar Vural (2011-2) conducted a study with six preservice science teachers to determine their understanding of chromosomes and their perspectives regarding teaching this concept. A semi-structured interview technique was used in their study and it was found that students did not thoroughly assimilate the chromosome concept. As noted, studies were intensely conducted at every academic level using different data collection tools. The drawing-writing technique is used to determine cognitive structures and misconceptions. Atasoy (2004) expressed that drawing reveals hidden and unexpected parts of concepts as well as multiple dimensions of understanding over a single dimension. Additionally, it was shown that a change in the expected outcome of an educational process can be determined with drawings, even if it is subjective. While the drawing-writing technique can be used as an instrument, it can also be used as a visual teaching and learning tool. Quillin and Thomas (2015) argued that teaching and understanding biology without visual presentations is difficult and that visual presentations are powerful tools that simplify the complex and make the invisible visible.

1.1 Purpose

The aim of this study was to determine 10th grade students' cognitive structures and misconceptions about chromosome and homologous chromosome concepts using the drawing-writing technique. This study will seek to answer these research questions:

1. What is the students' level of cognitive structures about the chromosome concept?
2. What are the misconceptions in students' drawings about the chromosome concept?
3. What are the misconceptions expressed in students' explanations about the chromosome concept?
4. What is the students' level of cognitive structures about the homologous chromosome concept?
5. What are the misconceptions in students' drawings about the homologous chromosome concept?
6. What are the misconceptions expressed in students' explanations about the homologous chromosome concept?

2. Material and Methods

2.1 Participants

140 10th-grade students from two different public schools in the province of Konya, Turkey participated in the study. The students were informed about the study process and voluntarily participated. The average age of the participants was 16 and 55.71% were female and 44.29% were male. Gender difference was not relevant to the study. Literature supports that there are not large gender differences in similar studies (Kibbos et al., 2004). In the Secondary High School 10th Grade Cell Division and Reproduction Unit, the chromosome and homologous chromosome concept is presented in the Cell Cycle topic. Students are expected to understand the chromosome and homologous chromosome concept in this unit prior to the next topic, reproduction.

2.2 Data collection

In this study, the drawing-writing technique was used to determine the students' cognitive structures and misconceptions about chromosome and homologous chromosome concepts. Students were given A4 paper and asked to draw an image that first comes to mind about the concepts of chromosome and homologous chromosome, to identify the elements, and to explain the concept they drew with a written explanation. A number was designated for each student's worksheet. Two experts examined and coded the chromosome and homologous chromosome concepts separately to ensure the reliability of the drawing-writing technique. The data analysis is presented in Table 1. Experts' opinions were consulted about the planning, implementation and analysis sections of the study for validation. The reliability formula (Reliability = Agreement / Agreement + Disagreement) suggested by Miles and

Huberman (1994) was used to calculate the reliability of this study. According to this formula, the reliability was found to be 81%. A reliability value higher than 80% is accepted to be reliable (Miles & Huberman, 1994); therefore, the technique used in this study is reliable. In addition, drawing examples from the students' worksheets were included in the findings section.

2.3 Data Analysis

The category levels presented in Table 1 were used in analyzing the data obtained by DWT (drawing-writing technique). Other studies using this technique helped determine these categories (Bahar, Özel, Prokop, & Uşak, 2008; Çelikler & Topal, 2011; Derman & Yaran, 2017; Dikmenli, 2010). Drawings in each category were included in the findings section.

Table 1: The Levels and Level Context used to analyze the data obtained by the drawing-writing technique

Levels	Levels' Context
Level 1	No information/drawing
Level 2	Information/drawings include non-representational and inaccurate or alternative concepts (including comics which have no scientific focus and contradicts scientific knowledge)
Level 3	Partial or incomplete information/drawings (scientific information/drawing which is at an acceptable level and includes some basis of scientific ideas)
Level 4	Information/drawing with conceptual representation (Completely accurate and appropriate to scientific knowledge)

3. Results

The drawing-writing technique was presented to students to determine their cognitive structures and misconceptions about the construction of chromosome and homologous chromosomes. The students' drawings were analyzed according to the levels and contexts given in Table 1. The analysis determined the students have misconceptions about the concepts of chromosome and homologous chromosomes. Figure 1 shows the student's drawing which depicts misconceptions about the chromosome design (Level 2). In this drawing, the student did not identify the centromere structure of the chromosome. Figure 4 illustrates another student's drawing where s/he drew the necessary design regarding the homologous chromosome; however, s/he depicted a design of synapsis and cytochrome over the centromere. Since this student demonstrated a misconception, this drawing was considered a Level 2. Figure 2 represents a students' partial drawing. Evaluating this chromosome, the student made a drawing which is correct and doesn't include a misconception. The student identified the centromere and drew the sister chromatid, however did not indicate the name or indicate the presence of DNA. Therefore, this drawing was placed under partial drawings and considered to be a Level 3. A student's drawing of homologous chromosome at Level 3 was presented in Figure 5. This student did not demonstrate

any misconception; however, the sister chromatids and DNA were not specified in this drawing.

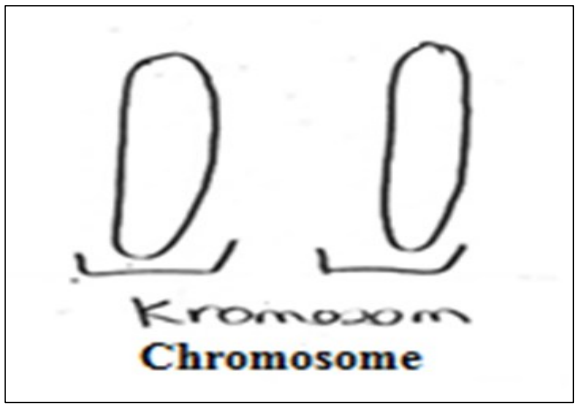

Figure 1: Examples of chromosomes Level 2
(non-representational and drawings with misconceptions) (Student 118)

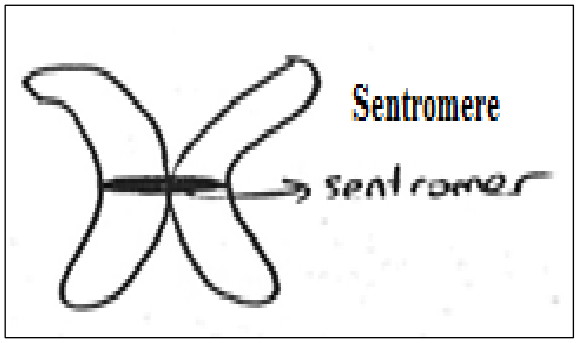

Figure 2: Examples of chromosomes Level 3
(partial drawing) (Student 87)

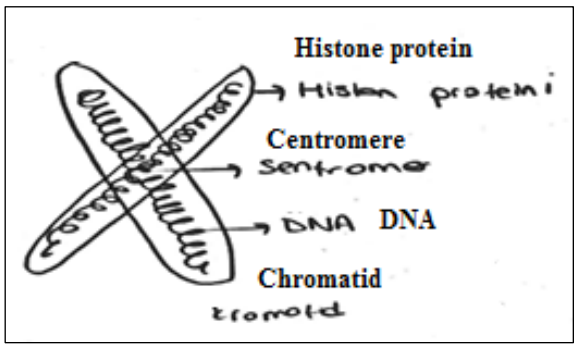

Figure 3: Examples of chromosomes Level 4
(comprehensive representation drawing) (Student 114)

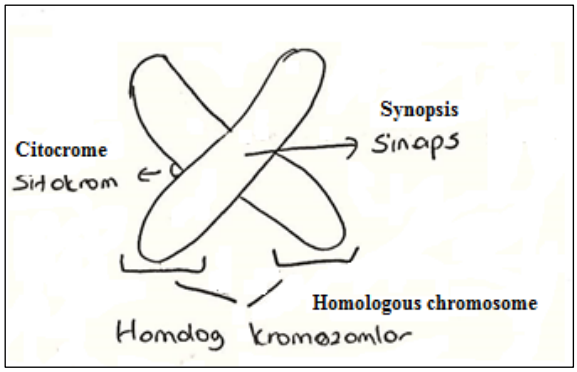

Figure 4: Examples of homologous chromosomes' Level 2 (non-representational and drawings with misconceptions) (Student 118)

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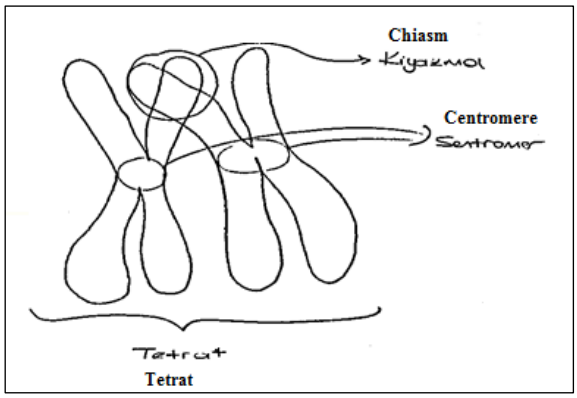

Figure 5: Examples of homologous chromosomes Level 3 (partial drawing) (Student 4)

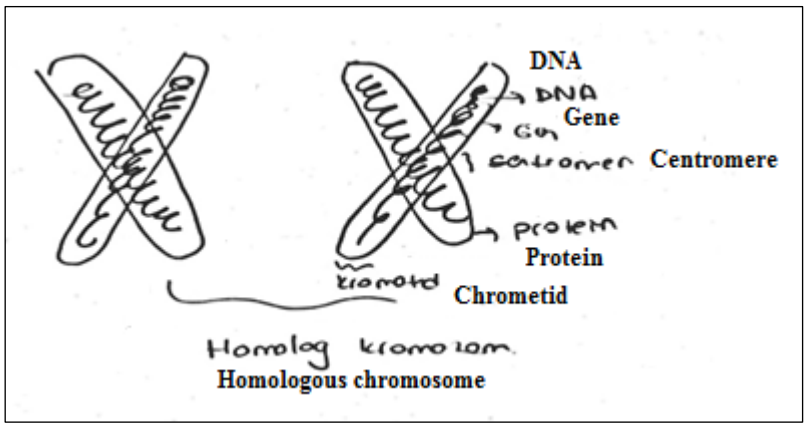

Figure 6: Examples of homologous chromosomes' level 4 (Comprehensive representation drawing) (Student 114)

The students' drawings of chromosome and homologous chromosome at Level 4 were given in Figures 3 and 6. In these drawings, student drew the sister chromatids, DNA, centromere and completely identified them in the diagram. The student drew a homologous chromosome and specified the elements in the depiction.

Table 2 shows the numbers and percentages of concepts the students used in their drawings of chromosome and homologous chromosome. The most frequently

used concepts were centromere (25%), DNA (17.9%), sister chromatids (15.7%) and kinetochore (11.4%). Synapsis (4.3%), chiasma (3.6%), allele gene (3.6%) and centrosome (2.1%), which were considered a misconception, were included in the students' drawings. Students most frequently used centromere (16.4%), allele gene (12.1%), locus (9.3%), synapsis (8.6%) and chromatid (7.85%) concepts in their drawings regarding the homologous chromosome.

Table 2: The most frequent elements for chromosome and homologous chromosome

Elements for chromosome	**n**	**%**	**Elements for homologous chromosome**	**n**	**%**
Centromere	35	25	Centromere	23	16.4
DNA	25	17.9	Allele gene	17	12.1
Sister chromatid	22	15.7	Locus	13	9.3
Kinetochore	16	11.4	Synapsis	12	8.6
Gene	11	7.85	Chromatid	11	7.85
Synapsis	6	4.3	Kinetochore	9	6.4
Protein	5	3.6	Mother-father	8	5.7
Nucleus	5	3.6	Chiasma	8	5.7
Chiasma	5	3.6	Gene	6	4.3
Allele	5	3.6	Crossing-over	6	4.3
Spindle apparatus	5	3.6	DNA	5	3.6
Chromatin	3	2.1	Tetrad	5	3.6
Centrosome	3	2.1	Adenine-Guanine-Cytosine - thymine	4	2.9
Nucleotide	3	2.1	Hair color	3	2.1
Human	2	1.4	Character	3	2.1
Adenine-Guanine-Cytosine - thymine	2	1.4	Eye Color	2	1.4
Histon protein	2	1.4	Chromosome	2	1.4
Chromatin apparatus	1	0.7	Diversity	1	0.7
Helical spring	1	0.7	Secondary node	1	0.7
Mother	1	0.7	Nucleus	1	0.7
Organic base	1	0.7	Anaphase I	1	0.7
Phosphor	1	0.7	Spindle apparatus	1	0.7
Locus	1	0.7	Modules	1	0.7
Character	1	0.7	Cestus	1	0.7
			XX-XY chromosome	1	0.7

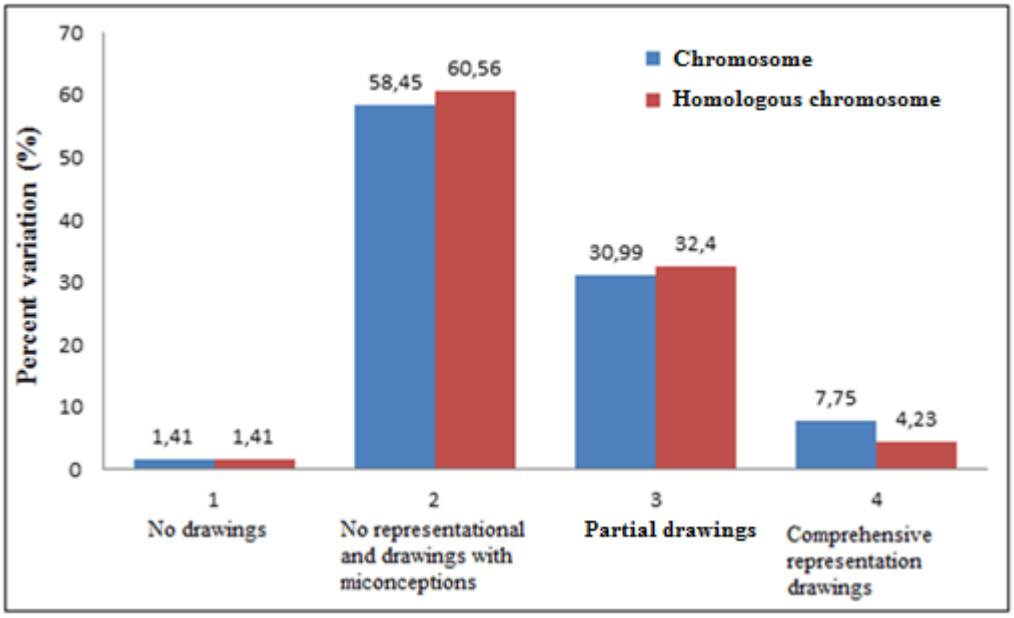

Figure 7: Comparison of high School students' understanding of the chromosome and homologous chromosome by analysis of their drawing

Figure 7 illustrates the percentages of the students' level scores regarding their drawings of chromosome and homologous chromosomes. This shows the students' drawings were primarily at Level 2. Of the Level 2 drawings, 58.45% were about chromosomes and 60.56% were about homologous chromosomes. These drawings included misconceptions. The number of drawings of homologous chromosomes including a misconception is higher than the number of drawings of chromosomes including a misconception.

The misconceptions obtained from both the students' drawings and explanations are given below. The students' drawings and explanations of chromosomes inferred that they confuse the sister chromatid with the homologous chromosome. They specified the presence of synapsis and allele gene between the sister chromatids, which indicates they did not fully understand the concepts related to homologous chromosomes.

Table 3: Misconception in the drawings of chromosome

Misconceptions	**n**
1. Sister chromatids in chromosomes combine making a synapsis.	7
2. There are mutual allele genes in sister chromatids in chromosomes.	6
3. There is not any centromere in chromosomes.	2
4. Chromosomes combine making a chiasm.	3
5. Sister chromatids in chromosomes combine with the centrosome.	3
6. The structure of chromosomes consists of a DNA.	2

Table 4: Misconceptions in the interviews about the chromosome

Misconception	n
1. Synapsis and tetrad events take place in all chromosomes.	3
2. A chromosome is found in the structure of DNA.	1
3. Spindle apparatuses formed by the centrosome constitute chromosomes by shortening and loosening.	1
4. Chromosomes are the building blocks constituting DNA .	5
5. A missing chromosome causes Down's syndrome.	1
6. The chromosome consists of DNA and has a kinetochore in its middle.	1

The students thought that sister chromatids form the homologous chromosome and one of these sister chromatids comes from the mother and the other comes from the father. This result indicates that the students have the most inaccurate understanding about the sister chromatids and homologous chromosomes (Tables 5,6).

Table 5: Misconceptions in the drawings of homologous chromosomes

Misconceptions	n
1. Sister chromatids form the homologous chromosome.	7
2. Two sister chromosomes make a synapsis with each other.	5
3. Homologous chromosomes are chromosomes having the same genes.	7
4. Homologous chromosomes consist of modules.	2
5. Endpoints of chromosomes are known as kinetochore.	2
6. Endpoints of chromosomes are known as chiasma.	2

Table 6: Misconceptions in the interviews about the homologous chromosome

Misconceptions	n
1. Homologous chromosomes are sister chromatids, one from the mother and one from the father.	3
2. Homologous chromosomes are sexual chromosomes, one from the mother and one from the father.	3
3. Homologous chromosomes make crossing-over in meiosis and mitosis.	1
4. Two or more chromosomes form homologous chromosomes.	1
5. Homologous chromosomes are the chromosomes whose mutual genes are always the same.	2
6. DNA matching takes place in the formation of homologous chromosomes.	1
7. Chromosomes are archaeal bacteria.	1
8. All chromosomes are called homologous chromosomes.	1

4. Discussion

This study aimed to determine 10th-grade secondary school students' cognitive structures and misconceptions about chromosome and homologous chromosome concepts using the drawing-writing technique. The students' drawings were analyzed according to four levels which were presented in Table 1. With this analysis, the students' misconceptions were also investigated. The results of the students' levels of drawing were presented in Figure 7. According to this figure, 1.41% of the students'

drawings were at the Level 1. The students at this level did not make a drawing. The students who made drawings about both the chromosome and homologous chromosome at Level 2 were unable to describe these concepts and had misconceptions. 58.45% of the drawings of chromosome and 60.56% of the drawings of homologous chromosome were at Level 2. It can be argued that students have a lack of understanding particularly in the homologous chromosome concept. 30.99% of the students' drawings of chromosome and 32.4% of the students' drawings of homologous chromosome were at the Level 3, which indicates a partial drawing and has no misconception. According to this result, it can be asserted that students are knowledgeable about the homologous chromosomes; however, they have misconceptions. The students' drawings at Level 4 regarding chromosome was 7.75% and homologous chromosome was 4.23%. In general, these students have misconceptions about chromosome and in particular homologous chromosome. The most frequently used concepts in the students' drawings about chromosomes and homologous chromosomes were centromeres (25%), DNA (17.9%), and sister chromatids (15.7%). The students used the concepts that should be primarily addressed in the structure of a chromosome at a low level. They also used the kinetochore concept in their drawings by 11.4%. Looking at the homologous chromosome, students most frequently used the centromere concept (16.5%), followed by the allele gene (12.1%) and locus (9.3%). The concepts synapsis, chiasma and mother-father were recorded 8.6%, 5.7% and 5.7, respectively. The students drew the allele gene 12.1% and included the crossing-over event by 4.3% (Table 2) in the homologous chromosome structure. In their drawings of chromosome, the students included DNA and sister chromatid concepts at a low level. Nevertheless, there were misconceptions about these concepts in their drawings and explanations. Some of these misconceptions were: Sister chromatids in chromosomes combine making a synapsis, mutual genes in sister chromatids are called allele genes, and sister chromatids combine with chiasma and centrosome (Table 3). Moreover, the students have these misconceptions in their explanations: chromosomes are found in the structure of DNA, chromosomes consist of spindle apparatuses, chromosomes are the building blocks constituting DNA, and synapsis and tetrad events take place between sister chromatids (Table 4). In the students' drawings and explanations, it is evident that students generally confuse the concepts related to the chromosome and homologous chromosome with each other. Some of the students' misconceptions in the chromosome concept were: chromosomes consist of chromatid apparatus and sister chromatids are connected with each other at many points. These misconceptions taken from the students' drawings and explanations of chromosome indicate that the students have insufficient understanding about the structure and function of this concept. The students expressed these misconceptions regarding the centromere part of the chromosome: kinetochore, nucleus, crossing-over, chiasma, and spindle apparatus in the structure of chromosome (instead of DNA). Students confused the chromosome, homologous chromosome and sister chromatids with each other. The students' have a common misconception in their explanations and drawings of both

chromosome and homologous chromosome as seen in these results: homologous chromosomes are exactly the same as each other, loci in homologous chromosomes carry the same gene, part replacement in chromosomes take place in both mitosis and meiosis, and homologous chromosomes are formed with DNA matching (Figures 1, 4, & 7 and Tables 5 & 6). Similarly, Emre and Bahşi (2006) in their study with preservice science teachers found that the participants are unable to establish the connection among chromosome, gene and DNA. The inability to establish this connection leads to a contradiction in concepts. In the aforementioned study, 75% of the students expressed that the crossing-over event takes place between sister chromatids in meiosis. Topçu and Şahin Pekmez (2009) in their study with 128 secondary school students aged 14 to15 years old found that a vast majority of the students were unable to explain the function of chromosomes.

Similar results were obtained in the earlier identified studies. There are inadequate cognitive structures at every level of education concerning these concepts. However, these concepts are fundamental to mitosis and meiosis which can be considered as the chromosome movement and exchange. Atılboz (2004) studied high school freshmen and used open-ended questions to determine their misconceptions. The results showed that students did not fully comprehend the basic concepts of DNA, chromosome, chromatid, homologous chromosome, haploid, and diploid. Consequently, they had difficulties in understanding basic events in the mitosis and meiosis process and chromosome behaviors. Temelli (2006) conducted a study with 184 high school students and found that 35.3% of the students comprehend the relationship between DNA and chromosomes while the remaining students do not. Moreover, only one-third of the teachers know the functions of chromosomes. Studies conducted with secondary and high school students indicate that students lack understanding about chromosome, DNA and gene concepts. In general, this lack of understanding about chromosomes and homologous chromosomes where abstract concepts are intensely used creates an obstacle for the next topic of cell division. For this reason, these concepts should be fully addressed within the scope of a syllabus, textbooks and teaching. Solutions should be presented accordingly.

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