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Comparing Traditional Teaching of Mitosis and Meiosis With 3D Animations Instruction Method in Real Classroom

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Abstract: Genetics concepts are difficult to both learn and teach. Especially mitosis and meiosis include complex molecular mechanisms difficult for the student to comprehend. In addition, traditional instructional approaches focus exclusively on the molecular level. Relating the molecular level up to the cellular remains a difficult step for students. Previous studies revealed misconceptions about the two cell division processes, the biological significance of their outcome and their implications. This paper proposes educational activities about mitosis and meiosis using 3D animations instruction and presents the results of their application in real classroom, within the usual course in Greek high school students. The results were compared with the traditional teaching approach using a textbook and lecture format. The findings revealed that 3D animations educational scenario was more effective and improved students' performance in case of meiosis rather than mitosis.

Key words: biology education, mitosis, meiosis, 3D animations, traditional teaching

1. Introduction

Molecular Genetics concepts are extremely challenging to teach. In particular, cell division is difficult to teach both to school and to university students (Chattopadhyay, 2012; Lewis, 2000a). Firstly, the mechanisms of mitosis and meiosis are extremely complex, unfamiliar to high school biology curriculum up to that point. Secondly, understanding these procedures presupposes knowledge and comprehension of the structure of the cell, fundamental genetics concepts and fertilization (Stockwell et al., 2015). Thirdly, students have none or little awareness of the dynamic nature of the cell. They are not only required to fill the gap between cellular and molecular level phenomena, but also to deepen to complex molecular mechanisms which in combination becomes extremely cognitively challenging. Previous studies revealed that school students or higher secondary students find hard time in order to understand the primary differences between the division mechanisms of the two processes, the importance of the formation of haploid germ cells, the significance of the maintenance of the same number of chromosomes during mitosis, or the recombination of the genetic material during meiosis and the implications therein (Chattopadhyay, 2005; Lewis, 2000a; Lewis, 2000b).

An effective way to depict effectively abstract molecular phenomena such as cell division or to fill the gap from genotype (molecular level-genes or chromosomes) to phenotype (macroscopic level-traits) is to present to the students the dynamic nature of the cell (Marbach-Ad & Stavy, 2000). Traditional teaching methods fail to connect the three principal levels of organization: macroscopic, microscopic and molecular level of organization

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(Slish, 2000). On the other hand, 3D animations may offer advantages over textbook. They resemble the cell environment and therefore consist powerful means to depict the complexities of cellular and molecular structures and dynamics (Glynn, 1998). Furthermore, instruction using 3D animations adds auditory engagement to visual and therefore enhances comprehension (Campbell, 2008; McGill, 2008; Schönborn & Anderson, 2006). In addition, 3D animations can be reproduced at home (Slish, 2000), and are proved more engaging and motivating (Stockwell et al., 2015).

The value of 3D scientific animations stands out in previous studies. Video assignments proved significant at stimulating students' interest and engagement to science (Stockwell et al., 2015). McGill revealed that scientific visualization algorithms are powerful cell biology teaching tools. They give life to molecular phenomena and present them interactively in correct shape, time and place in the cell (McGill, 2008).

Prior literature about mitosis and meiosis concerns higher secondary level (Chattopadhyay, 2005; Chattopadhyay, 2012), or secondary school students (Lewis, 2000a; Lewis, 2000b). To our knowledge no such research comparing the traditional instructional approach with the use of textbook and lecture from the teacher with the use of 3D animations has taken place. This paper combines these both. It presents teaching scenario about mitosis and meiosis in high school students in a pragmatic classroom, within the usual course, with usual peers and instructor. Students were not aware they participated in research. So the trial was conducted in real classroom conditions. Furthermore, it compares two teaching strategies, using 3D animations in a first classroom or the traditional teaching method (textbook and pictures therein) in a second classroom.

Current research took place in two different classrooms of 2nd grade students (aged 15–16) of the 5th High School of the city of Kalamata, Greece. Each classroom was attended by equivalent numbers of students (19 and 20 students respectively) and students with high and low scores to biology (Stockwell et al., 2015). Students are distributed to each classroom in alphabetical order. In the first classroom the instructor described the processes while the learners watched the scientific 3D visualizations. When necessary the instructor interrupted and posed questions in order to improve the visual literacy of the students (Schönborn & Anderson, 2006). To the second classroom teaching tool was only the textbook (text and pictures therein). To both classrooms the same questionnaire was administered.

2. Methodology

A written questionnaire was administered to both classrooms. It included fixed-answer type questions with two possible answers YES or NO. The questions concern the aim of mitosis and meiosis, their molecular mechanisms and their final products (Chattopadhyay, 2012; Lewis et al., 2000a). The questionnaire was distributed to all students present in the class at the begging of the session. Each student answered anonymously. The teacher took special care to avoid any exchange of information among students. Misconceptions and alternative concepts were identified at the time. The same questionnaire was distributed at the end of the session and the students were asked to fill it in from the beginning anonymously again. One school hour (45 min) was administered to mitosis and another to meiosis. In the first classroom the instructor described the processes using scientific 3D visualizations, while in the second classroom teaching tool was only the textbook for both mitosis and meiosis. Videos were carefully selected to cover the same material with the textbook. Statistical analysis of the questionnaires before and at the end of each session was performed by t-Test.

3. Pedagogical Goals of the Educational Literary Programs

1) The student should recognize that the outcome of mitosis is two daughter cells identical in quality and quantity of the genetic material with the parent cell.

2) The student should be able to deepen to the transformations of genetic material throughout meiosis.

3) The student should embrace the importance of creation of haploid sex cells (eggs and sperm) to fertilization and formation of the zygote.

4) The student should recognize that sex cells of the same individual carry different genetic information (as a result of recombination of genetic material through crossing over and of random distribution of parental chromosomes during meiosis I).

4. Educational Scenario

4.1 Pedagogical Activity 1 — Mitosis

In the first classroom the teaching tool was 3D animations. Video concerning the mechanism and the formation of two identical cells as final products of mitosis was presented to the class[1]. In the second classroom the teaching tool was only the textbook (text and pictures therein). At the beginning of the session the students of both classrooms completed anonymously the questionnaire 1 (Table 1) by answering YES or NO to each question. The questionnaires were collected by the instructor. At the end of the session the same blank questionnaire was administered to the students again. The students completed it anonymously once more.

4.2 Pedagogical Activity 2 — Meiosis

In the first classroom meiosis was now taught through 3D animations. Video concerning the mechanism and the formation of four haploid sex cells as final products of meiosis was presented to the class[2]. In the second classroom the teaching tool was again only the textbook (text and pictures therein). At the beginning and at the end of the session the students of both classrooms completed anonymously the questionnaire 2 (Appendix - Table 2) by answering YES or NO to each question. The procedure was the same described above in Pedagogical activity 1.

5. Results and Discussion

The first questionnaire includes questions about mitosis (cell division and repair) of skin cells. Table 1 presents the questions and summarizes the results before and after the teaching session about mitosis in both classrooms. In response to the questions concerning the type of division by mitosis and the function of daughter cells (question 5) and DNA replication (question 11), correct answers increased by the use of 3D animations. On the contrary, the questions asking about the correct number of genes to the daughter cells (question 6) and the genetic material (question 4), proved that the use of textbook and the pictures therein was more effective. Although the majority of the answers correctly indicated that genetic material would remain the same after mitosis that was not the case for the chromosome number (question 3). Students seem to be unclear as to the physical relationship between chromosomes and genetic material or were confused by terminology. These findings are also

[1] https://www.youtube.com/watch?v=AhgRhXl7w_g.
[2] https://www.youtube.com/watch?v=D1_-mQS_FZ0.

mentioned elsewhere (Chattopadhyay, 2005; Lewis, 2000a). Another misconception revealed is that old cells have less chromosomes (question 7). Both teaching methods failed to reverse it. Similar results were also mentioned to another study (Chattopadhyay, 2005).

Table 1 Questions Included in Questionnaire 1 About Mitosis. Percentage of Correct Answers Before and After Teaching Mitosis in Both Classrooms Are Given. The Rest From 100% Stands for The Percentage of the Wrong Answers. The Asterisk* Indicates the Questions That Had A Statistically Significant Difference.

Question		Before video instruction	After video instruction	Before traditional instruction	After traditional instruction
		% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	Skin cells produced after a trauma are different from the original damaged ones.	50.0	30.0	68.4	47.4
2	The original skin cell divides by mitosis.	80.0	80.0	78.9	68.4
3	The parent cell contains 46 chromosomes. It divides and each daughter cell contains 92 chromosomes.	95.0	90.0	63.2	57.9
4	Genetic material to daughter cells reduces to half.	42.9	50.0	52.6	68.4
5	Daughter skin cells and parent cell perform the same function.	45.0	65.0	78.9	78.9
6	New skin cells and original cell contain the same genes	78.9	65.0	60.0	68.4
7	New skin cells carry double chromosomes. Their number decreases due to aging.	45.0	45.0	68.4	42.1
8	Original skin cell divides again and again to produce many new skin cells.	20.0	50,0	10,5*	47,4*
9	Sperm cells are produced by mitotic division.	60.0	47.4	78.9	73.7
10	Liver cells undergo mitotic division.	70.0	65.0	61.1	84.2
11	DNA replication precedes mitosis.	65.0	75.0	73.7	68.4
12	Sister chromatids of each chromosome are split evenly between the two daughter cells.	80.0	73.7	64.7	63.2
13	During the mechanism of mitosis cytokinesis follows the separation of the chromosomes.	70.0	70.0	27.8	44.4
14	At the start of prophase, chromatin fibers begin condensing into chromosomes.	30.0	63.2	70.0	84.2
15	During metaphase the sister chromatids are pulled to opposite ends of the cell. The spindle fibres contract, breaking the chromatids at the centromere and moving them to opposite poles of the cell.	75.0	65.0	42.1	47.4

The questions about the cell types where mitosis applies neither teaching tool enhanced the correct answers (questions 9, 10). A possible explanation could be a luck of differentiation between somatic and reproductive tissues. Similar results revealed confusion about which type of cell division occurs in somatic tissues or the gonads (Lewis, 2000a). As far as the mechanism of mitosis and the chromosomes' movement both teaching tools enhanced the correct answers at the end of each the session (questions 12–15).

Table 2 presents the questions and summarizes the results before and after the teaching session about meiosis in both classrooms. The second questionnaire concerning meiosis proved the use of 3D visualizations of great pedagogical value. In contrast with the traditional teaching approach, the use of video enhanced the percentage of correct responses. In particular the students correctly recognized the right number of chromosomes of egg and sperm (questions 1, 2), the somatic tissue where meiosis takes place (questions 5, 6), the formation of new genetic material (question 3), the discrimination between meiosis and fertilization (question 7) or the right number of the

zygote chromosomes (question 13).

Table 2 Questions Included in Questionnaire 2 About Meiosis. Percentage of Correct Answers Before and After Teaching Meiosis in Both Classrooms Are Given. The Rest From 100% Stands for the Percentage of the Wrong Answers. The Asterisk* Indicates the Questions That Had A Statistically Significant Difference.

Question		Before video instruction	After video instruction	Before traditional instruction	After traditional instruction
		% Correct answers	% Correct answers	% Correct answers	% Correct answers
1	Ovary cell contains 46 chromosomes. It divides and the egg produced carries 46 chromosomes as well.	52.9	64.7	61.1	66.7
2	Testis cell contains 46 chromosomes. The cell divides producing four non-identical sperm cells, each consisting of one chromatid of the homologous chromosome pair.	64.7	70.6	83.3	94.4
3	Sperm cells consists of the same genetic material with the original testis cell.	35.3*	70.6*	55.6	66.7
4	Meiosis contributes to the formation of genetic variation.	76.5	64.7	58.8	55.6
5	A skin cell undergoes meiotic division.	41.2	46.7	44.4	33.3
6	Ovary cells divide by meiosis.	47.1	70.6	44.4	33.3
7	There is no difference between meiosis and fertilization.	64.7	70.6	88.2	70.6
8	Egg cells are haploid cells, while skin cells are diploid cells.	76.5	64.7	81.3	77.8
9	DNA replication precedes meiosis.	68.8	40.0	50.0*	77.8*
10	At the end of meiosis the egg contains one extra chromosome. The presence of extra genetic material has no impact on future offspring.	58.8	58.8	75.0	72.2
11	During fertilization the egg contributes 5 chromosomes and the sperm cell 6 chromosomes.	88.2	94.1	44.4	66.7
12	The egg carries only one X chromosome.	76.5*	35.3*	61.1	47.1
13	Human zygote bears 23 chromosomes.	50.0	64.7	61.1	55.6
14	The outcome of meiosis I is two cells. Each one of these cells undergoes a second division, called meiosis II, which results in the formation of four gametes.	70.6	58.8	77.8	44.4
15	During Prophase I each chromosome finds its homologous counterpart.	70.6	47.1	61.1	72.2
16	During Metaphase I the homologous chromosomes pairs line up randomly and align themselves on either side of the equator.	52.9	47.1	44.4	44.4
17	At the end of Telophase II two haploid cells are formed. Their chromosomes consists of two sister chromatids attached to the centromere.	35.3	29.4	44.4	33.3
18	Each one of the two cells produced by Meiosis II undergoes a new division with identical stages to Meiosis I.	47.1	47.1	44.4	41.2

Another misconception found, also mentioned elsewhere (Lewis, 2000a) is awareness about the products of meiosis. Genetic information differs due to crossing over, recombination and random distribution of chromosomes. In another study 14.5% of college students could not make any distinction between the products of the two cell

divisions. Furthermore, 12% did not respond at all (Chattopadhyay, 2005). In our case video instruction doubled the correct answers from 35.5 % to 70.6% (question 3). It is evident that the use of 3D animations proved splendid teaching tool for students to endorse that the original cell and sperm cell do not contain the same genetic material.

Although, the majority of students were aware that genetic information will be different, they luck to combine it with variation and evolutionary process (question 4). This result is in line with the course syllabus, since the course of Evolution follows chronologically the Genetics. Neither method was effective as far as the mechanism of meiosis and the movement of chromosomes during the processes of meiosis I and II, were concerned (questions 14–18). A possible explanation is that the students didn't have enough time to embrace such intricate and dense phenomena.

6. Educational Implications

These findings suggest the difficulty of the complex mechanisms and concepts concerning cell division at school level. Especially in Genetics the traditional teaching approach is suboptimal for many students. Many limitations of the traditional teaching methods are surpassed by alternative pedagogy. The use of 3D animations adds auditory engagement to visual and allows a deeper emphasis of the importance of genetics concepts. Overall, the results reveal that the paradigm of 3D animations for science education provides foundational knowledge better and proved more effective pedagogical tool than the traditional teaching approaches as far as the dynamic procedures within the cell take place (McGill, 2008). Additional teaching aids like laboratory techniques or the use of models or blended learning can serve a critical role improving the level of understanding of cell division and genetics in general (Chattopadhyay, 2005, Stockwell et al., 2015).

Moreover, misconceptions at early school level when addressed at the right time lead to more effective learning in the future academic career of the students. Previous study revealed that misconceptions about mitosis and meiosis among higher secondary or college students originated from earlier school years and proved stable and pervasive. Only 38.5% of college students predicted the correct number of chromosomes the daughter skin cell would carry after mitosis. Of these only 41% properly explained their prediction. Similar results occurred about the number of chromosomes in the gametes formation by meiosis. 45.5% answered correctly, only 33% of them for the right reason. Students had little awareness of the basic differences of the two procedures and furthermore meiosis appeared to be confused with fertilization (Chattopadhyay, 2012).

7. Conclusions

At high school level the use of 3D animations improved students' performance. Especially in the case of meiosis, 3D scientific visualizations enhanced comprehension and reversed misconceptions relative to the purposes and products of meiosis. That was not the case for the traditional teaching approach. These results reveal that 3D animations could be an effective teaching tool. Therefore, in order to foster a deeper comprehension, Science Educational Literary Programs should incorporate 3D animations to traditional teaching method.

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