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Learning the process of the cell cycle in 13- and 14 year-olds

Učenja procesa celičnega cikla pri 13 in 14 letnikih

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Abstract: The new biology curriculum introduced the teaching of mitosis to 13- and 14-year-olds students in Slovenia. Mitosis is a challenging topic for this age. In our study, we enrolled a sample group of 95 students to check if the method of teaching mitosis first described by Danieley (1990) could be effective for students of this age. Prior to the survey, the students had not yet dealt with the division of cells; most of them did not even know that all living organisms are made of cells. The results show that this method is effective; enrolled students used logical reasoning and were thus able to understand how the events in the cell cycle and the process of mitosis follow one another. The majority of students correctly arranged 15 drawings presenting the stages of the cell cycle after the lesson, and their knowledge retention was satisfactory. Incorrect placements of drawings did not show any typical mistakes in students thinking about the cell cycle that should create specific concerns for the biology teachers.

Keywords: mitosis, cell cycle, understanding, biology, 13-year-olds, 14-year-olds

Izvleček: Novi učni načrt v Sloveniji je vpeljal poučevanje mitoze za učence, stare 13 in 14 let. Mitoza je za to starost zahtevna tema. V naši raziskavi smo na vzorcu 95 učencev preverili, ali je metoda poučevanja mitoze, ki jo je prva predstavila Danieley (1990), lahko učinkovita za učence te starosti. Učenci pred raziskavo še niso obravnavali delitve celice, večina tudi ni vedela, da so vsi organizmi zgrajeni iz celic. Rezultati kažejo, da je uporabljena metoda učinkovita; učenci so z uporabo logičnega razmišljanja bili sposobni razumeti, kako si sledijo dogodki v procesu celičnega cikla in mitoze. Večina učencev je po učni uri pravilno razporedila 15 slik, ki predstavljajo faze celičnega cikla. Njihovo znanje je bilo zadovoljivo trajno. Nepravilne razporeditve niso pokazale nikakršnih značilnih napak v razmišljanju učencev glede celičnega cikla, na katere bi morali biti učitelji biologije pri poučevanju posebej pozorni.

Ključne besede: mitoza, celični cikel, razumevanje, biologija, 13-letniki, 14-letniki

Introduction

Cell biology is a wide, complex, and rapidly evolving field of biology which, as we know from school practice, causes a lot of trouble for students as well as for teachers. Highly competent teachers are needed for effective teaching of cell biology; research has shown, however, that prospective teachers of biology have a deficit of cell biology knowledge (Dikmenli, 2010). Students have difficulties understanding and integrating this knowledge (Castro, 2009; Lewis and Kattmann, 2004; Locke and McDermid, 2005; Mbajiorgu et al., 2007; Štraus et al., 2006; Venville and

Treagust 1998; Venville et al., 2005; Williams et al., 2012). Many students learn science topics as isolated facts and do not construct links between old and new knowledge. As a consequence they find it difficult to understand subsequent topics (Smith, 1988). BouJaoude (as cited in Cavallo, 1996) even says that students consistently learn by memorizing, and as a result form misconceptions about scientific concepts. In addition, the factual way of obtaining knowledge can be frustrating for students, and therefore draws them away from science in school and later in career choices (Novak, 1988).

In the modern world it is essential to understand the basic concepts of cell biology to obtain efficient scientific literacy of citizens (Venville et al., 2005). Therefore, several authors and institutions around the world have attempted to improve the teaching of cell biology in order to change students' misconceptions in the most reliable way, while at the same time helping students achieve high levels of expertise that includes understanding and the ability to apply acquired knowledge. Wyn and Stegink (2000) proposed actively involving middle, high school and college students in the learning of mitosis by role-playing. Similarly, sock and yarn modeling can engage middle, high school, and college students in the lesson of meiosis (Stavroulakis, 2005). Locke and McDermid (2005) found undergraduate students responded well when engaged and activated in the manipulation of a pool of noodles which represented chromosomes and chromatids in mitosis. Danieley (1990; see also Shields, 2006) and Lawson (1991) proposed teaching mitosis through a learning cycle. Lawson's lesson includes exploring actual plant tissues and an investigation and was developed for use in high schools. Danieley's lesson includes observing the drawings of individual cells and focuses on understanding development in the process of mitosis.

In Slovenia, elementary school provides education from grades 1 to 9. The students are generally aged between 6 and 14. We are now in the period of the introduction of the new biology curriculum for the grades 8 and 9, so we are looking for solutions that would enable the general population to understand the foundations of cell biology. Teachers are faced with problems of: (1) how to present cell biology content in the most comprehensive manner; and (2) how to provide students with what they'll need for everyday life, as well as a solid foundation for any further education. When deciding what will be taught and in what order, it is important to consider that students find mechanisms in cell biology difficult to understand because of the difficulty in presenting this topic with no specific instruments (Mbajiorgu et al., 2007). This topic also requires a certain level of abstract thinking (Banet and Ayuso, 2000; Smith and Sims, 1992). Lawson and Thompson (1988) found, that the reasoning ability of studentswas statistically and significantly related to the number of misconceptions in genetics. Students on the level of concrete operations held more misconceptions. On the other hand, Smith and Sims (1992) came to the conclusion that formal operational thought is not strictly required for the solution of the majority of classical genetics problems, and that students possess the cognitive skills that are needed to address the most typical problems in classical genetics. In addition, there are technics of teaching available that contribute to a greater understanding of genetics concepts.

Purpose of the study

We started from the realization that students in general have difficulties in learning biological processes (Dikmenli, 2010; Strgar, 2010; Straus, 2006; Venville et al., 2005). Cavallo (1996) found that there were very few students who were able to connect conceptual knowledge of meiosis with procedural knowledge, so phases of the process of meiosis. She says that we should consider whether the greater amount of knowledge about the stages of meiosis is necessary for a better understanding of meiosis. She also suggested that it should be checked, whether detailed instructions on the stages of meiosis may present an obstacle or interfere with students in forming the concepts of meiosis. We found that the method of teaching/learning a similar process i.e. the process of mitosis first presented by Danieley (1990; see also Shieds, 2006) was in accord with Cavallo (1996). It focuses on the logic of the process of mitosis and avoids giving too many details. Besides that Danieley's (1990) method also employs a non-traditional sequence of learning content, which could have some impact on the level of understanding of mitosis in students. Teachers in teaching genetics mostly stick to traditional teaching methods and traditional sequencing of learning content, and use similar learning strategies (Watts and Jofili, 1998).

In 2011 a new curriculum came into use in Slovenia, according to which students start to learn mitosis at the age of 13 (beginning in school year 2012–2013). The previous curriculum has anticipated teaching mitosis at the age of 14 (so one year later). The purpose of our study, therefore, was to establish whether Danieley's (1990) method could be an effective way of teaching mitosis for 13 year-olds.

Material and methods

Participants

The study was conducted in the autumn of 2011 on a group of 95 students. In this sample there were 39 (41.1%) students aged 13 (8^{th} grade of elementary school in the Slovenian school system) and 56 (58.9%) students aged 14 (9^{th} grade). The sample group consisted of 51 (53.7%) girls and 44 (46.3%) boys. None of the enrolled had learned about mitosis at school yet at the time of this study.

The students in our group were an average population according to the results of their self-evaluation: They were moderately successful in biology (M = 3.15, SD = 0.977), biology was somewhat easier to nearly as difficult for them as for their classmates (M = 3.32, SD = 0.941). They learned biology materials at a moderate speed in comparison to their classmates (M = 2.99, SD = 1.092). On these three issues the 13-year-olds responded similarly to 14-year-olds (all ps > 0.05). On two issues girls responded similarly to boys (all ps > 0.05). However, there was a difference between genders in one question; boys more often thought that biology was easier for them than for their classmates (Mann- Whitney test, U = 787.000, z = –2.540, p < 0.05).

We also checked students' attitudes toward biology. The students in our sample did not want to learn biology (M = 2.39, SD = 1.147), they did not want to be taught more biology in school (M = 2.26, SD = 1.206), they did not want a job which would use biology (M = 2.04, SD = 1.077), and were undecided whether knowledge of biology would help them in everyday life (M = 3.10, SD = 1.183). The 13-year-olds responded similarly to the 14-year-olds (all ps > 0.05), and the girls responded similarly to boys (all ps > 0.05).

Tests

<u>Pre-test (before the lesson)</u>

We prepared a pre-test which consists of three units. The first unit was a short knowledge test to check the students' knowledge before the lesson. We asked them one basic question concerning cells ("Which of the following organisms are made of cells: bacterium, bee, human, oak, paramecium and fungus?") and four questions concerning mitosis ("What is mitosis?", "Where does it take place?", "When does it take place?", and "Why does it take place?").

The second unit of the pre-test was a worksheet with 15 drawings of the stages of the cell cycle (Shields, 2006). The drawings in the worksheet were focused on the movement of chromosomes. Stage 1 represented a cell with a visible nucleus; stage 2 represented a cell with a chromatin. Stages 3–9 showed a logical sequence, starting from two-chromatid chromosomes which then get separated, to where eventually each chromatid moves to the opposite pole of the cell. Stages 10–13 showed another logical sequence in which the division of the cell begins, thus, the mitotic spindle is less and less visible. Stage 14 represented an almost divided cell with a chromatin, and stage 15 represented the two daughter cells with visible nuclei. The 15 drawings of the stages of the cell cycle were randomly mixed in a worksheet. Students who had not learned these subjects in school by the time of our research had to arrange drawings in a correct sequence using only logic.

The third unit of the pre-test consisted of seven questions, to which the students responded with the help of a 5-point Likert scale (1 – completely disagree, 5 – completely agree), giving their agreement with given statements. This is how we gathered data about the performance of students in biology class (3 questions), and about their attitude towards biology (4 questions).

Post-test (immediately after the lesson)

Immediately after the lesson, all students again arranged 15 drawings of the stages of the cell cycle in a worksheet. The purpose of this test was to establish the quality and quantity of knowledge that students mastered during the lesson.

Late post-test (four weeks after the lesson)

An identical worksheet for the classification of the 15 drawings of the stages of the cell cycle was given to the students again four weeks after the lesson. The purpose of this test was to establish the retention level of knowledge that students mastered during the lesson.

Procedure

We began the lesson with a short introduction and instructions for work, followed by pre-testing (10 minutes). Each pupil (1) answered five questions, which tested the knowledge of biology, (2) assessed seven statesments on a Likert scale, and (3) completed the worksheet with 15 drawings of stages of the cell cycle. Everyone made two identical copies of the worksheet, where one was given to the teacher and the second was needed to continue the lesson. This was followed by a lesson (30 minutes), during which students learned about the processes of the cell cycle and particularly of mitosis and its importance. We used the method first proposed by Danieley (1990); the worksheet was taken from the book Biology Inquiries (Shields, 2006).

In this phase students were put in small groups to review their completed worksheets of 15 drawings of stages of the cell cycle, and discuss the placements of all drawings. It was important that each pupil explained his placements and described them in his own words. Then the teacher led a whole-class discussion. The whole class discussed the placement of each drawing and gave reasons for that particular placement. It was essential that in this part of the lesson, the teacher did not use professional biological terms such as chromosome, DNA, gene, mitotic spindle, etc., which is a classic way of teaching mitosis (Jofili and Watts, 1998). Throughout the discussion everyone used terms that are used in everyday language; the reason why mitosis is so challenging for students is because students learn about the process, and at the same time they first encounter a lot of new expressions, of usually foreign origin (Knippels et al., 2005). After the students had understood the sequence of events in the process of the cell cycle, the teacher introduced professional terminology and expanded on new topics such as why cells divide, when do new cells generate in the living being, how do living beings grow, and that mitosis is a process that enables the precise transfer of genetic information to both daughter cells. The objectives of this lesson were two, students should: (1) understand the sequence of events in the cell cycle; and (2) understand what the cell cycle and mitosis are, as well as where, when, and why they take place.

Students arranged the 15 drawings of stages of the cell cycle once more at the end of the lesson (post-test, 5 minutes), and then again four weeks later (late post-test, 5 minutes).

Statistical analysis

The data analysis was carried out using SPSS statistical software (version 20). The Mann- Whitney test was used to identify statistically significant differences between girls and boys, and between 13- and 14 year-olds. A paired-samples *t*-test was used to identify statistically significant differences among the results of three consecutive tests (pre-test, post-test, late post-test). The effect size estimate *r* was calculated. A principal component analysis (PCA) was conducted on 15 items with orthogonal rotation (varimax) to establish in how many components the stages of mitosis will be positioned. The value of the Kaiser-Meyer-Olkin measure of sampling adequacy was 0.78, which means that our sample size was adequate for PCA. Bartlett's test of sphericity was highly significant ($\chi^2 = 1303.649$, df = 105, $p < 0.001$), indicating that correlations between items were sufficiently large for PCA.

Results

Knowledge test

Living beings are made of cells

Most students were aware of the fact that cells are the building blocks of human beings (85% correct answers). But there were fewer correct answers about other organisms: bee (67%), bacterium (53%), oak (51%), fungus (48%), and paramecium (42%). The differences between the responses of students of different ages were only statistically significant for the bacterium (Mann Whitney test, $U = 774.000, z = -2.244, p = 0.025$), and human beings (Mann Whitney test, $U = 724.500, z = -3.750, p < 0.001$). In bacterium more knowledge was shown by 13-year-olds, while in humans more knowledge was shown by 14-year-olds. Differences between the knowledge of girls and boys were not found (all ps > 0.05).

What is mitosis, and where, when, and why it takes place

On each of the four questions on mitosis (what is mitosis, where, when, and why it takes place) only 1.1–3.2% of students responded. None of them correctly answered the first three questions, only the fourth question (why mitosis takes place) was correctly answered by 2.1% of students. These students wrote that mitosis is required for reproduction or cell division. The 13-year-olds showed similar knowledge as the 14-year-olds (all ps > 0.05). The differences between the knowledge of girls and boys were not found (all ps> 0.05).

Arranging 15 drawings of stages in the cell cycle

Before the lesson, 78% of those enrolled correctly placed drawings of the first stage of the cell cycle and 20–33% of students correctly placed drawings of the other 14 stages (Fig. 1). Immediately after the lesson, the first stage was correctly placed by all students; other drawings (of the other 14 stages) were correctly placed by 88–98% of students. Therefore, after the lesson students were able to arrange all drawings much more accurately than before the lesson. Four weeks after the lesson the number of correct answers were slightly lower than immediately after the lesson, but still very high; the drawing of first stage of the cell cycle was correctly placed by 98% of the students and drawings of the other 14 stages of the cell cycle by 73–86% of the students.

Students placed most of the drawings not only in their correct positions, but also in almost

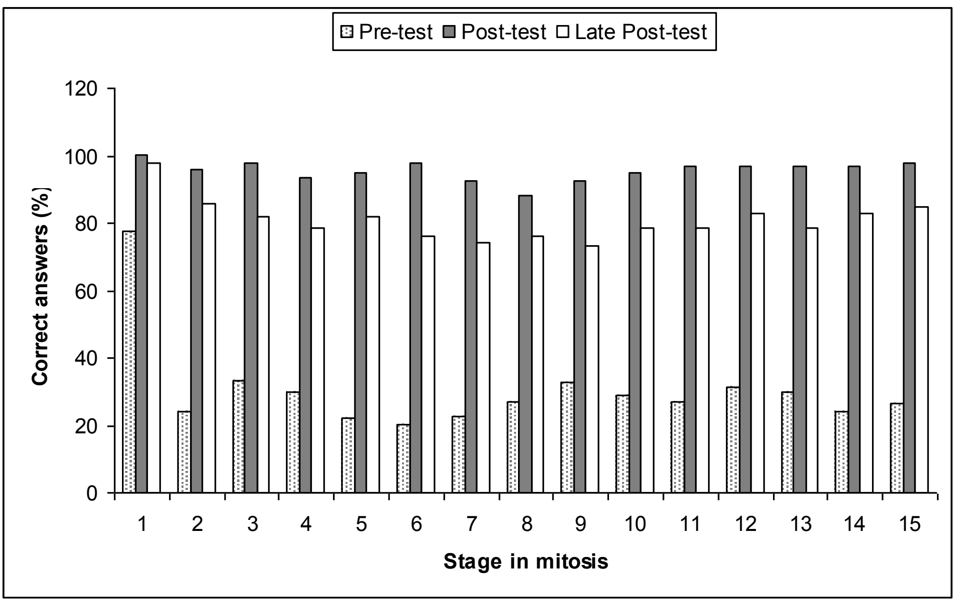

Figure 1: Share of correct placements of 15 drawings of stages in the cell cycle before the lesson, immediately after the lesson, and four weeks after the lesson (N = 95).

Slika 1: Deleži pravilnih razvrstitev 15 slik faz celičnega cikla pred poukom, takoj po njem in štiri tedne kasneje (N = 95).

all possible incorrect positions (Tab. 1). Before the lesson the range of positions for individual drawings was 10–14. Immediately after the lesson the range was much smaller than before the lesson (0–7 positions). The only exception was stage 8, with the range of 13 that did not change compared to the test before the lesson. Therefore, we see that the knowledge of students after the lesson was better. Four weeks after the lesson the range expanded again to 9–13 positions. The exception was stage 12 with a range of 6.

The analysis showed that students placed 12 stages statistically significantly better immediately after the lesson than before the lesson. Only in stages 2, 9, and 11 the difference was not statistically significant (Tab. 2). The effect size of changes after the lesson was large in stages 10, 14, and 15, in stages 1, 3–8, 12, and 13 the effect size was medium, and in stages 2, 9, and 11 it was small or negligible. Four weeks after the lesson students' achievements decreased; this decrease was statistically significant in seven stages (stages 3, 4, 6, 9, 10, 14, 15). The effect size of the decrease four weeks after the lesson was medium in stages 3 and 10, and small in the rest of the stages.

Table 1: Median and range of placements of 15 drawings of stages in the cell cycle before the lesson, immediately after the lesson, and four weeks after the lesson (N = 95).

Tabela 1: Mediana in razpon razvrstitev 15 slik faz celičnega cikla pred poukom, takoj po njem in štiri tedne kasneje (N = 95).

	Pre-test		*Post-test*		*Late Post-test*	
Stage of mitosis	*Mdn*	*Range*	*Mdn*	*Range*	*Mdn*	*Range*
1	1	14	1	0	1	12
2	3	14	2	6	2	12
3	3	14	3	7	3	12
4	6	12	4	6	4	10
5	6.5	11	5	6	5	11
6	6	13	6	4	6	12
7	8	10	7	7	7	12
8	8	13	8	13	8	11
9	8	12	9	6	9	12
10	10	11	10	6	10	9
11	11	12	11	2	11	10
12	12	13	12	3	12	6
13	12	14	13	2	13	11
14	13	14	14	7	14	13
15	4	14	15	5	15	13

Four components were extracted, which explained 78.17% of the total variance (Tab. 3). The items that cluster on the same components suggest that component 1 represents two types of a cell: (1) a cell with duplicated chromosomes consisting of two sister chromatids in prophase and metaphase; and (2) a cell with daughter chromosomes that are being pulled toward the poles, while cytokinesis starts in anaphase. Component 2 represents a cell with daughter chromosomes that are being pulled toward the poles before cytokinesis starts in anaphase. Component 3 represents one cell or two cells with formed nucleus in interphase, and component 4 represents a cell with chromatin in early prophase and late telophase.

Stages 3–6 and stages 10–13 (from total of 15 stages) were included in the first component. The first sequence of four drawings (stages 3–6) represents mitosis from prophase to metaphase, the latter sequence of four drawings (stages 10–13) represents anaphase and telophase. The two sequences represent the starting and the finishing parts of mitosis. The results therefore show that students were able to recognise the first and the latter sequence and to arrange them correctly.

Table 2: Statistically significant differences in placement of 15 drawings of stages in the cell cycle before the lesson, immediately after the lesson, and four weeks after the lesson (Paired-samples *t*-test; N = 95). Statistically significant values are shown in bold type.
Tabela 2: Statistično pomembne razlike v razporeditvi 15 slik faz celičnega cikla pred učno uro, takoj po njej in štiri tedne kasneje (Paired-samples *t*-test; N = 95). Statistično pomembne razlike so prikazane v poudarjenem tisku.

	Pre-test/Post-test				Post-test/Late Post-test			
Stage of mitosis	*t*	*df*	*p* (2-tailed)	*r* (effect size)	*t*	*df*	*p* (2-tailed)	*r* (effect size)
1	5.169	92	**< 0.01**	0.32	–1.313	92	0.193	0.14
2	1.567	92	0.118	0.10	–0.764	92	0.447	0.08
3	7.021	92	**< 0.01**	0.42	–3.028	92	**0.03**	0.30
4	–59.000	92	**< 0.01**	0.31	2.505	92	**0.014**	0.25
5	7.474	92	**< 0.01**	0.44	–1.975	92	0.051	0.20
6	6.454	92	**< 0.01**	0.39	–2.736	92	**0.07**	0.27
7	5.031	92	**< 0.01**	0.32	–0.573	92	0.568	0.06
8	7.044	92	**< 0.01**	0.42	–1.744	92	0.084	0.18
9	–0.154	92	0.877	0.01	–2.413	92	**0.018**	0.24
10	–11.671	92	**< 0.01**	0.61	3.363	92	**0.01**	0.33
11	–0.614	92	0.540	0.04	–0.856	92	0.394	0.09
12	–3.924	92	**< 0.01**	0.25	–0.071	92	0.944	0.01
13	–6.201	92	**< 0.01**	0.38	0.660	92	0.511	0.07
14	–8.543	92	**< 0.01**	0.49	2.758	92	**0.07**	0.28
15	–10.240	92	**< 0.01**	0.56	2.687	92	**0.09**	0.27

Table 3: Summary of principal component analysis for 15 drawings of the stages in the cell cycle.
Tabela 3: Zbirnik analize glavnih komponent za 15 slik faz celičnega cikla.

	Rotated factor loadings			
Stage of mitosis	Duplicated chromosomes; daughter chromosomes are pulled toward the poles and cytokinesis starts	Daughter chromosomes are pulled toward the poles	Nucleus	Chromatin
3	**–0.915**	0.020	0.226	0.071
4	**–0.914**	0.073	0.218	0.189
12	**0.912**	–0.039	0.256	0.158
5	**–0.907**	0.149	0.196	0.165
11	**0.880**	0.015	0.249	0.256
13	**0.880**	0.012	0.148	0.085
6	**–0.823**	0.114	0.251	0.223
10	**0.754**	0.100	0.266	0.285
8	–0.015	**0.862**	–0.102	–0.091
7	–0.078	**0.699**	0.043	0.137
9	0.095	**0.641**	0.057	0.187
14	0.375	**–0.580**	–0.122	**–0.529**
1	–0.150	0.090	**–0.740**	0.016
15	0.391	–0.312	**–0.702**	0.310
2	–0.084	–0.248	0.209	**–0.894**
Eigenvalue	6.55	2.59	1.52	1.07
% of variance	43.69	17.26	10.10	7.12

Stages 7–9 were included into the second component; they all represent a sequence of events in anaphase. Stages 1 and 15 were included in the third component; they both represent interphase, the first one is a parent cell, the second one two daughter cells. Stages 2 and 14 were included in the fourth component; the first represents a parent cell in early prophase, and the second developing daughter cells in late telophase. The main elements in cells in these two drawings are thin threads of uncoiled chromosomes (chromatin). So we can see that the students recognised the logical sequences of stages which helped them arranging the drawings in the correct order. Difficulties were encountered with intermediate stages or the connection of these partial sequences in the entire sequence of 15 drawings.

Discussion

One of the fundamental processes in biology which represents the biggest problems for students is also mitosis. Usually it is taught in the traditional way, starting with a presentation of the technical, biological terms such as chromosome, DNA, gene, mitotic spindle, etc. (Watts and Jofili, 1998). Danieley (1990) and Shields (2006) proposed a different instructional strategy. This one is focused on the logic of stages in the process of mitosis and the cell cycle. Teaching/learning of mitosis in the way suggested by Danieley (1990) makes the most sense if carried out on those who are only just starting to learn about mitosis. Students try to independently place the 15 images of intermixed phases of the cell cycle in a logical sequence. After students understand the course of events in the cell cycle, biological terms for structures and stages of the cell cycle are introduced to upgrade the knowledge of biology. Our study focused on students aged 13 and 14, and gave us better insight into students' capacity to understand this process, which can be used in planning activities and teaching the cell cycle.

Knowledge test

In our study we intended to address mitosis, therefore we were interested in whether students have the basic knowledge into which they can reasonably place mitosis (Banet and Ayuso, 2000). First of all we tested students for their knowledge of the fact that cells are the building blocks of all living beings. In the test there was a human and a bee as representatives of the animal kingdom. Most students were aware of the fact that the human (85%) and the bee (67%) are built of cells. This result suggests that students best mastered the concept of cellular structure in connection with animals. Only 42–53% of students knew that representatives of other kingdoms (bacteria, protists, fungi, and plants) are also composed of cells. There were two statistically significant differences between 13- and 14-year olds. The 13-year olds knew better than the 14-year olds that bacteria were made of cells, while the 14-year olds knew better that humans were made of cells. This difference could be explained by the biology curriculum, as the 13-year-olds were learning about the system of living beings including bacteria in the year this study was conducted, while the 14-year-olds were learning about the human body. There was also one statistically significant difference in knowledge between genders: the girls knew better than the boys that bees are made of cells. This fact could be connected to the fact that bees are insects with positive connotation, which appeals to girls more than to boys (Fakin, 2012).

The results show that majority of 13-year-olds did not acquire the concept of the cellular structure of living things, i.e. the fact that all living beings are made from cells. This suggests that teaching strategies, which enrolled students have experienced in primary school, were not successful in bringing about the understanding of this phenomenon. Banet and Ayuso (2000) who studied the biology knowledge of 15-year-olds also came to the conclusion that most students do not know that all living beings are built from cells. We also tested students for their knowledge of mitosis (what is mitosis; where, when, and why it takes place). The very low response rate and only 2.1% of correct answers show that students in our sample had not been familiar with mitosis before the lesson. Such a result was expected because our school system did not include mitosis and cell division into the curriculum for students less than 13 years old before school year 2012–2013.

Arranging 15 drawings of stages in mitosis

Students first sorted 15 pictures of the stages of the cell cycle before the lesson. The purpose of this first arranging of drawings was to find out how the students think so we could then work with that (Newton, 2004). Before the lesson, the drawing of the first phase was correctly placed by 78% of students, while the other 14 drawings were correctly placed by 20–33% of students (Fig. 1).

The first phase represented a single parent cell with a visible nucleus (interphase of a cell cycle), which was a typical cell, familiar to students. It was also the first drawing in the sequence of 15 drawings in the worksheet. Our speculation is that both these facts helped the majority of students correctly identify this drawing as the first stage in the cell cycle.

Students could potentially place each drawing in any of the 15 positions. We found that before the lesson the 14 drawings were most often placed in correct positions while one drawing was most often placed in incorrect position (stage 15; 42% of the students placed it in the position of stage 2). Drawing 15 represented two daughter cells with visible nuclei (interphase of a cell cycle). The results suggest that students recognised a typical cell as represented in drawings 1 and 15, and therefore placed them one after the other. The rests of the 13 drawings having no visible nucleus were viewed as atypical according to the knowledge that students had at the time. As Fisher (1985) stated, it is more difficult to generate new knowledge than to retrieve something one already knows. When confronted with an answer that seems right, students tend to avoid any additional solving of a problem and they choose this answer. We think that this is the reason why so many students placed drawings 1 and 15 separately from the rest of the 13 drawings.

Apart from this there were no other frequent incorrect placements of drawings. The most common mistake was placements of drawings close to the correct position, but not quite correctly: just before or just after the correct position and two places before or two places after the correct position. Students with such placements, even if they were incorrect, however, showed that they recognized the similarity of images. Therefore, these errors were not considered critical. These results indicate that students did not make any typical mistakes that could reflect a misunderstanding to which the teacher should be especially attentive when teaching mitosis and the cell cycle using this method.

The results show that students gained an understanding of the events in the cell cycle during the lesson, and that strategy implemented in the lesson was an effective way of teaching/learning this process.

We deduced this from the results, which show that immediately after the lesson students placed 12 drawings statistically significantly more correctly than before the lesson (Tab. 2). The range of incorrect placements was also highly reduced (0–7 incorrect positions) for most of the drawings (Tab. 1) compared to the test before the lesson. Only stage 2 which represents a single cell with a chromatin stood out (drawing 8). Its range immediately after the lesson was 13, and did not change in comparison to the pre-test. This can be explained by the fact that this stage does not logically fit into the sequence, so students did not know where to place it.

We found that students' achievements were lower four weeks after the lesson compared to the test immediately after the lesson. 98% of students correctly placed the drawing of the first stage in the cell cycle (Fig. 1) four weeks after the lesson. The other 14 drawings were correctly placed by 73–86% students. The range of incorrect placements was a bit higher in comparison to the test immediately after the lesson (Tab. 1), and 8 drawings were placed statistically significantly different than immediately after the lesson (Tab. 2). However, the effect size of these changes was small for 13 drawings and medium for two drawings, which suggests that the knowledge students gained by this method was sufficiently permanent.

The presented method is therefore an effective way of teaching/learning the basics of the process of the cell cycle. Students gained an understanding of the basic frame of the cell cycle. This represents a firm hierarchical concept needed for meaningful learning (Mintzes et al., 2001). Once students gain this it can be gradually upgraded. How far knowledge should be upgraded depends on the skills of students and on the curricula.

The new biology curriculum in Slovenia which was first implemented in school year 2012–2013, and introduced teaching mitosis to 13-year-olds. Most students at this age are capable of logical reasoning. The method of teaching we tested in our survey focuses on recognising and understanding the logical sequence of events in the cell cycle. Based on our results we can conclude that this method is effective and suitable for teaching both 13- and 14-year-olds equally. Students could solve the problem using logic. Similar cases where students could successfully solve problems using algorithmic methods were reported in other fields, for example in teaching meiosis by Stewart and Dale (as cited in Cavallo, 1992) and Williams et al. (2012).

In the lesson presented, the teacher let the students to describe the events and the drawings of stages of the cell cycle using colloquial language. This is because extensive genetic terminology adds to the difficulties that students experience (Knippels et al., 2005); it does not contribute to an understanding of events and puts students off the subject. During the lesson students spontaneously named structures and drawings according to what these structures reminded them of: as spaghetti (chromatin) and butterflies (duplicated chromosomes consisting of sister chromatids). Professional terminology was presented to students only after they had already understood the course of events in the cell cycle. This, perhaps not to our surprise, gained little understanding on the part of the biology teachers who were involved in the study. Most of the teachers found the use of such terminology too childish and inappropriate for a school situation.

We argue that teaching/learning should use this method to its advantage because it helps students gaining understanding of the process and is the opposite of learning by memorising. As stated in Watts and Jofili (1998), teachers should strive towards better quality of knowledge and not so much towards its quantity.

Another surprising fact concerning teachers emerged during our study. The general response concerning applying the presented method in class as a means of teaching/learning mitosis and the cell cycle was quite negative. Most teachers found it interesting only as a way of evaluating students' knowledge after the lesson. Reasons for that are yet to be thoroughly investigated. One of the possible explanations could be inertia to changes which suggests that classical way of teaching still predominates in our biology classes (Watts and Jofili, 1998).

Conclusions

The presented method proved to be effective in helping 13- and 14- year-old students understand the sequence of events in the cell cycle. The retention of students' knowledge was satisfactory. We also did not find any missconceptions in students that could impede the use of this method. Students were successful at learning and therefore not put off the subject of mitosis, as is too often likely to happen with this complex topic.

The only problem is that teachers are not yet sufficiently familiar with this method and those who are, do not favour it, comparing to the classical teaching strategy. Responsibilty is therefore on the work with in-service and pre-service teachers to make them understand alternative methods of teaching mitosis.

The method used in this study could be applied in teaching other biological topics, the most obvious being meisosis, but also such as photosinthesis, respiration, digestion, and others.

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