

Development of the concept of cell division through biology education

Razvoj koncepta celične delitve skozi biološko izobraževanje

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Abstract: School practice shows that a cell and the related cell division represent many problems for students as well as teachers. Students often hold misconceptions which form in everyday life under the influence of people with whom students live, as well as the media. Teachers are confronted with the problem of how to most effectively introduce this subject in class. They should enable students to understand basics of the cell and its implications as part of scientific literacy in the contemporary world. This survey used a test to assess the knowledge of students about cells. It included students on three levels of education; 13 year-olds, 15 year-olds, and 21 year-olds. The results showed that the knowledge of both younger groups was insufficient. The knowledge of the oldest group was substantially better, but still not satisfactory. It also showed that many students learn isolated facts and do not see the relationships between those facts. We believe that active methods of work in the classroom which are taken from everyday life could improve these results.

Key words: cell, cell division, genetics, education

Izvleček: Šolska praksa kaže, da predstavljata celica in z njo povezana celična delitev veliko težav učencem in tudi učiteljem. Učenci imajo pogosto napačne predstave, ki so se izoblikovale v vsakdanjem življenju pod vplivom ljudi, med katerimi učenci živijo, in medijev. Učitelji se srečujejo s problemom, kako tako vsebino predstaviti na čim bolj razumljiv način, saj morajo učenci razumeti temeljno znanje o celici in njegove implikacije kot del naravoslovne pismenosti v sodobnem svetu. V raziskavi smo z metodo testiranja preverili znanje učencev o izbranih temah s področja celice. Vključenih je bilo 171 učencev treh stopenj izobraževanja: 13-letniki, 15-letniki in 21-letniki. Rezultati so pokazali, da je znanje o celici pri obeh mlajših skupinah skromno, znanje najstarejše skupine pa sicer bistveno boljše, vendar še vedno nezadovoljivo. Opaziti je, da se mnogi učenci učijo naravoslovje kot izolirane podatke in ne vidijo medsebojnih odnosov, ki veljajo v naravi in svetu okoli njih. Domnevamo, da bi bilo to mogoče izboljšati z metodami dela, ki miselno aktivirajo učence in so povezane z vsakdanjim življenjem.

Ključne besede: celica, delitev celice, genetika, izobraževanje

Introduction

Understanding the basic concepts of biology is essential for the efficient scientific literacy of citizens (Venville et al. 2005) in the modern world. Therefore, various institutions around the world engaged in the renovation of teaching biology. They all strive to enable students to change their misconceptions and achieve high levels of expertise, which include understanding and the ability to apply acquired knowledge. Cell and the related cell division represent, as we know from school practice, many problems for students as well as teachers. For successful teaching we need teachers who are competent in the field of biology and possess educational skills. However, research has shown that prospective teachers of biology possess specific knowledge deficits (Dikmenli 2010, Šorgo and Ambrožič-Dolinšek 2009). Teachers tend to follow the traditional methods of teaching and the traditional sequence of learning content, and they use similar learning strategies (Watts and Jofili, 1998). Textbooks can be an important obstacle in learning biology as well. As showed the analysis by Knippels et al. (2005) biology textbooks failed to start on a phenomenon level and gradually descend to the lower levels. Besides, the conceptual relationships between interrelated chapters were not made explicit.

In accordance with the old biology curriculum (Verčkovnik et al. 2003) that was in use at the time of our study, students in Slovenia began to learn in detail the structure of cells and cell division at the age of 14. In 2011 a new curriculum came into force which requires that in school year 2012–2013 cell structure is taught to students three years younger, i.e. to 11 year-olds, and cell division to students one year younger, i.e. to 13 year-olds.

Recent research by Tomažič and Vidic (2011) showed that Slovenian students hold some misconceptions about the function of a cell. In our survey we wanted to establish what conceptions of the two scientific phenomena – the cell structure and the process of mitosis – are held by our students, and whether students have any false or alternative ideas about these topics. There has been a long debate in the science education literature about the extent to which the various conceptions held by students of scientific phenomena are to be seen as misconceptions or alternative conceptions.

With rare exceptions, it is generally held that there is a single valid scientific conception so that alternative conceptions are misconceptions (Reiss et al. 2007).

Misconceptions serve people quite well. For example, they help reduce the burden of processing information. Nor do misconceptions necessarily hinder the implementation of various practical tasks. For example, a person can have false notions about how objects move, but that person is nonetheless able to catch a ball (Fisher, 1985). The problem with misconceptions is adjusting them to newer and correct notions. According to Lewis and Kattmann (Castro 2009), students, even when they use proper biological vocabulary, may not use the expressions correctly. Students get lost in technical terminology; they do not connect the expressions and therefore cannot fully grasp the mechanisms behind the processes.

Students have problems understanding and connecting biological knowledge (Castro 2009, Lewis and Kattmann 2004, Locke and McDermid 2005, Mbajorgu et al. 2007, 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 (Novak 1988). BouJaoude (as cited in Cavallo 1996) even stated, that students develop misconceptions about science if they strictly learn by memorization. Similar findings for Slovenian primary and secondary levels of education are given by Fošnarčič et al. (2009), Jagodnik et al. (2009), Japelj Pavešič et al. (2012), and Štraus et al. (2007). Learning by memorization can make further science learning increasingly difficult and may deter many students from science in general (Novak 1988).

Teachers must therefore strive to better understand how to improve students' understanding and their inferential skills, which will in turn lead to higher-quality knowledge.

The purpose of the study

The purpose of our study was to assess the knowledge of cells and of cell division in students of three different age groups in Slovenia. In particular, we wanted to find out whether students have

any misconceptions about the cellular structure of organisms and cell division, and what these were. It was hypothesized that: (1) the knowledge and understanding of basic concepts concerning cells and cell division increases with the age of students in our sample; and that (2) students finishing general elementary education do not possess useful knowledge concerning cells and cell division, as stated in our national curriculum (Verčkovnik et al. 2003).

Material and methods

Participants

In Slovenia, elementary school provides education from grades 1 to 9. The pupils are generally aged between 6 and 14. Our survey included 171 students at three levels of education; 13 year-olds, 15 year-olds, and 21 year-olds (Tab. 1). Such a sample was chosen in order to get a wider range of possible responses, and thus make it easier to evaluate how age and the increasing level of education affect development and deeper understanding of the concept of cellular structure of all living beings, and of cell division.

Table 1: Students involved in the survey.
Tabela 1: Učenci, vključeni v raziskavo.

Students			
Age	Level of education in Slovenian school system	N	%
13 years	8 th grade of elementary school	58	34
15 years	1 st year of high school	87	51
21 years	3 rd year biology students (university)	26	15
Total		171	100

Knowledge test

The research method was quasi-experimental, which means that the participants in existing groups were compared by age or by level of education. As part of their regular classes the students completed a test with the following six questions:

1. Draw a cell and name its parts.
2. Which organisms are built from cells? (Multiple correct answers possible.)
 - a. Bacteria
 - b. Bee
 - c. Human
 - d. Oak
 - e. Fungus
3. How do cells multiply? Draw a picture.
4. In which organisms do cells multiply? (Multiple correct answers possible.)
 - a. In bacteria
 - b. In humans
 - c. In fungi
 - d. In plants
 - e. In animals
5. Why do cells in your body multiply?
6. When you cut your skin it eventually heals. Describe the process of healing.

The first four questions were given to all three groups of students, while the last two questions were only given to the 15 year-olds.

Students were first given three questions, in which we asked about basic knowledge that was explicitly stated in operational objectives in the curriculum for 14 year-olds (9th grade of elementary school in Slovenian school system) (Verčkovnik et al. 2003): students get to know the microscopic structure of a cell, students are able to draw a picture of a cell, and students get to know cell division. Then we asked them three additional questions in which they were expected to use basic

knowledge and apply it in given situations. Cell structure and cell division are topics that were a part of the Slovenian curriculum (Verčkovnik et al. 2003) first covered in the 9th grade (14 year-olds), so we expected that the youngest group in our sample i.e. eighth-graders (13 year-olds) wouldn't know it very well. The wound healing process (question 6) was not discussed in regular classes in any of the groups of students in our study, so we expected that this subject would not be well mastered. What we wanted to know was what naive notions on wound healing students

have and whether they were able to integrate knowledge about cells and cell division with wound healing.

Data analysis

The data was analysed with the SPSS 20 statistical program. The statistical significance of the differences between the responses of the three age groups was assessed by the Kruskal-Wallis test. The Jonckheere-Terpstra test was used to establish whether there is a significant trend in the data regarding the age of students. The effect size estimate r was also calculated.

Results and discussion

Results to two questions where students were asked to draw a picture (Question 1: Draw a cell and name its parts., Question 3: How do cells multiply? Draw a picture.) are based on a qualitative analysis, while others are based on a quantitative analysis.

Draw a cell and name its parts

The results we obtained clearly show that 13 year-olds only know the basic cell structure. More than half of them did not even answer the question and the drawings of cells by those who did were mostly simple. Next to the drawings they often indicated the parts they knew, which were the nucleus and the “envelope” or “membrane.” Drawings of cells by 15 year-olds were at first sight not very different from those of 13 year-olds. It is interesting that most of them drew animal cells, while some 13 year-olds also drew plant cells. Another survey (Yorek, Sahin, and Ugulu 2010) conducted on students from 11 to 17 years old came to similar conclusion: An increase was observed in the proportion of students who drew an animal cell as the grade level increased, along with a decrease in the proportion of the students who drew a plant cell. The cells drawn by the 15 year-olds in our study almost always included the nucleus which was also indicated, as well as some other components. All this and the fact that almost all the students answered the question suggest that 15 year-olds have a better command

of this subject than the 13 year-olds. Drawings of 13- and 15-year-olds represent the cell as two concentric circles, representing the cell membrane and the nucleus, representation for which Clément (2007) introduced the term the “fried-egg model.” This representation is lost in 21 year-olds, mainly due to a larger amount of other organelles with which they are familiar. The group of 21 year-olds showed the best knowledge of cell structure, as expected. They all answered the question, giving a drawing as well as a written response. Their drawings are very detailed, correct, and contain much more information than the drawings of the 15 year-olds. These results are similar to those reported by Saka et al. (2006).

Which organisms are built from cells?

We found statistically significant differences among students of different ages regarding knowledge of oak, bees, and fungi (Kruskal-Wallis test; $p < 0.05$), while not of humans and bacteria (Kruskal-Wallis test; $p > 0.05$) (Fig. 1). The Jonckheere-Terpstra test revealed a significant trend in the data for oak, bees, and fungi: students in higher grades had more knowledge than students in lower grades ($p < 0.001$, $r = 0.29-0.44$).

We found very poor results for bacteria. However, we believe that this result does not reflect a genuine lack of knowledge but is due to a large proportion of students’ literal understanding of the question that was stated in plural form (Which organisms are built from *cells*?). We therefore speculate that students actually showed knowledge here, as most of them answered that a single bacteria is not made of *cells*. Their responses therefore stress that bacteria is not a multicellular organism. This part of the survey should be repeated with a differently formulated question such as: “In which living beings is the cell the basic building unit?” to help us confirm or reject our assumption.

We established that 21 year-olds comprehend the concept of the cellular structure of all living beings, since almost all gave correct answers (96–100%). The lowest scores were achieved by the youngest group (13 year-olds), as was expected. This means that they have the lowest mastery of the concept of the cellular structure of living beings. However, to our surprise 13 year-olds answered

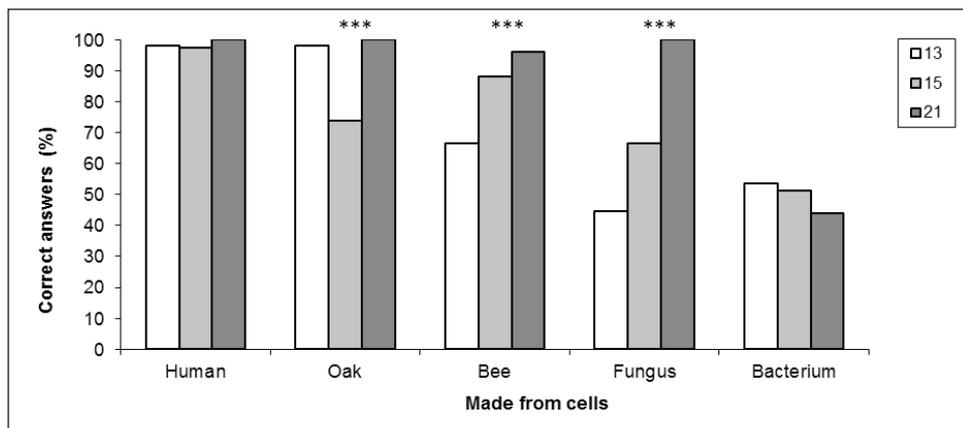


Figure 1: Percentages of 13 year-olds, 15 year-olds, and 21 year-olds who correctly answered the question: Which organisms are built from cells? (N = 171). Statistically significant differences, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Slika 1: Deleži 13-, 15- in 21-letnikov, ki so pravilno odgovorili na vprašanje: Kateri organizmi so zgrajeni iz celic? (N = 171). Statistično značilne razlike * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

much better than 15 year-olds, and almost as correct as 21 year-olds concerning the oak. This could be explained by the fact that in the time of our survey 13 year-olds were learning about the systematics of plants, therefore this topic was fresh and more familiar to them than it was to 15 year-olds. Low scores of 15 year-olds concerning oak can be explained by the fact, that more than a year had elapsed since they had learned this topic, so they may have forgotten it. The fact that 88% of 15 year-olds remembered that animals are made of cells, while only 74% think that plants are made of cells, and only 67% think that fungi are made of cells is probably due to the higher attractiveness of animals (Kinchin 1999, Strgar 2007, Wandersee and Schussler 2001).

Our results are very similar to those reported by Banet and Ayuso (2000). 20–25% of secondary school students in their survey thought that plants are not made of cells, and 30% thought that fungi are not made of cells.

How do cells multiply? Draw a picture.

13 year-old students made very simple cell division drawings, some of them suggesting they knew the cell forms a cleavage furrow; some also drew nuclei, but the responses very rarely

accompanied the picture. This is not surprising since this subject was not yet covered in school by 13 year-olds in our sample. In the 15 year-olds' drawings a qualitative conceptual leap was noticeable; it is clear that the students knew the basics of cell division, and they almost always drew the nucleus. Some even drew the chromosomes or the mitotic spindle. They drew both animal and plant cells. The results for 21 year-olds have shown that their conceptual understanding of cell division is relatively weak. They understand the basics of cell division, but surprisingly, there were no significant conceptual differences between their drawings and the drawings of 15 year-old students. These findings overlap with the findings of the study conducted by Dikmenli (2010) on a sample of 22 year-old, pre-service biology teachers. The drawings of 21 year-olds in our sample illustrated plant and animal cells, in part drawn simply and in part very precise. The drawings were mostly accompanied by text further explaining the processes.

In which organisms do cells multiply?

The results (Fig. 2) for all five groups of living beings show a comparatively similar picture regarding the notions of students at different age

levels. Understanding that cells in humans, plants, and animals divide is poorest with 13 year-olds and then improves with student age. However, even in the oldest group (21 year-olds) not everybody answered correctly. 13 year-olds associate cell division with animals, fungi, and particularly with bacteria, but not as much with humans and plants. 15 year-olds and 21 year-olds associate cell division mainly with humans, plants, and animals, and less with bacteria and fungi. Misconceptions concerning plants were already found by Wood-Robinson (1994), who stated that students of different ages in different parts of the world often thought that plants do not reproduce sexually. Our results seem logical, taking into consideration that students at the secondary level of education are expected to be able to identify living beings and to understand their cellular structure at least at the elementary level before they can start to learn cell division and genetics (Banet and Ayuso 2000).

The best knowledge of all the organisms was shown by the oldest group (21 year-olds). However, statistically significant differences between different age groups of students were found for all groups of organisms (Kruskal-Wallis test; $p < 0.05$), except for bacteria (Kruskal-Wallis test; $p > 0.05$). The Jonckheere-Terpstra test revealed a significant trend in the data for humans, plants, animals, and fungi: students in higher grades had

more knowledge than students in lower grades ($p < 0.001$, $r = 0.29-0.41$). This was expected, because cell division was first taught in school to 14 year-olds (Verčkovnik et al. 2003). The results of 15 year-olds therefore show that their knowledge about humans and plants had improved by almost 30% compared to 13- year-olds, and their knowledge about animals had improved by almost 20%.

To our surprise 15 year-olds were the ones who showed the least understanding of the fact that fungi and bacteria undergo cell division. This could be explained by possible development of alternative concepts, as year by year students gain new information. Also, as knowledge gets more complicated, and students forget some of the previously learned knowledge and may develop alternative concepts (Saka et al. 2006).

We observed obvious disparity of responses to the second question asking which living beings are built from cells and the fourth question asking in which organisms cells multiply (Fig. 3). This discrepancy indicates the troubling fact that students did not logically connect the individual learning sets. This means their knowledge remained fragmented and therefore not well understood. It may also be the case that students simultaneously have two different notions on the same subject, and the one they use depends on the situation in

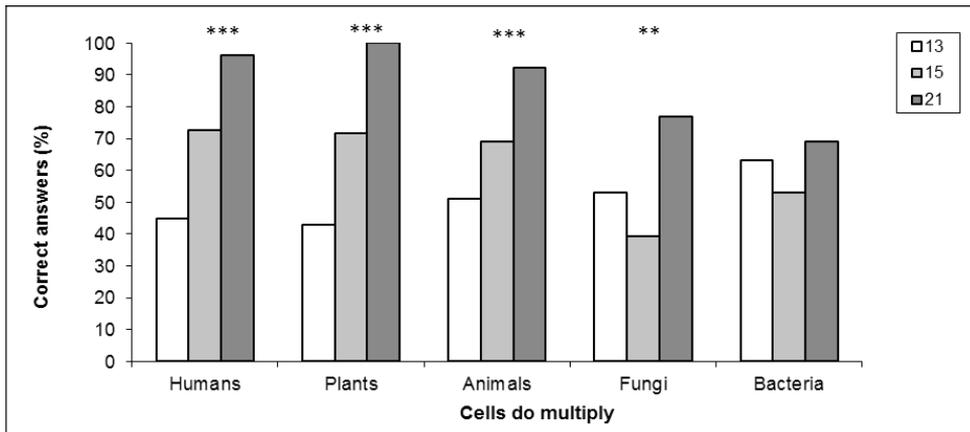


Figure 2: Percentages of 13 year-olds, 15 year-olds, and 21 year-olds who correctly answered the question: In which organisms do cells multiply? (N = 171). Statistically significant differences, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Slika 2: Deleži 13-, 15- in 21-letnikov, ki so pravilno odgovorili na vprašanje: V katerih organizmih se celice delijo? (N = 171). Statistično značilne razlike * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

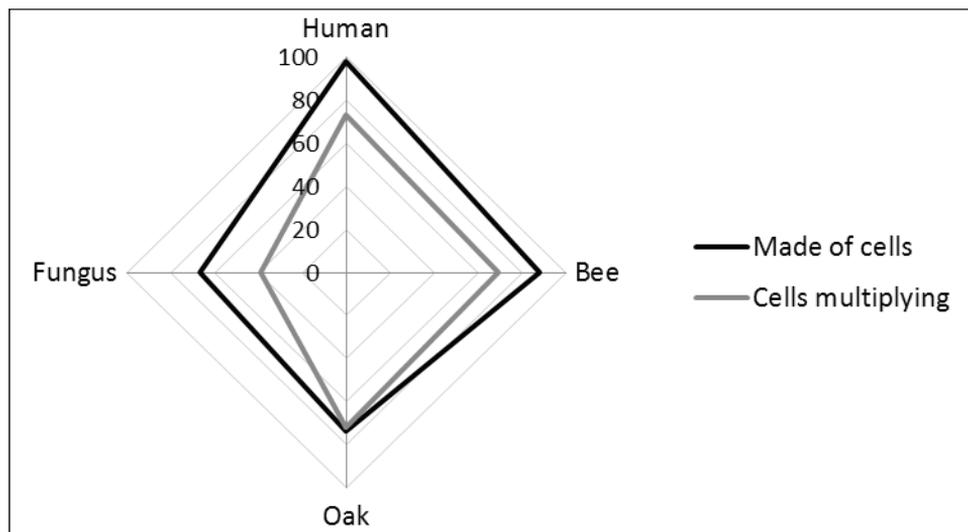


Figure 3: Percentages of 15 year-olds who know that the four given organisms are made of cells and percentages of 15 year-olds know that cells in these organisms multiply (N = 87).

Slika 3: Deleži 15-letnikov, ki vedo, da so štirje dani organizmi zgrajeni iz celic, in deleži 15-letnikov, ki vedo, da se celice v teh organizmih delijo (N = 87).

which they find themselves, as some research has also shown (Venville and Treagust, 1998).

Why do cells in your body multiply?

This question was only answered by 15 year-old students. Almost three quarters (72.7%) did not even attempt to answer, which lead to a conclusion that this subject is unfamiliar to them (Table 2). The percentage of correct answers was only 10.1%, for example “we grow,” “the body regenerates.” These responses were therefore correct, but not complete, as almost no one gave more than one reason for cell division.

Such results are not surprising since cell division was discussed in the 9th grade, but the emphasis was on the process and terminology, not on its purpose. In question 3, where students had to draw cell division, we found a satisfactory knowledge of process basics, but poor answers to question 5 indicate that a higher level of knowledge was not achieved. If students at lower levels of education learn these basic concepts meaningfully, they will build upon it successfully in their future

Table 2: Responses of 15 year-olds to the question: Why do cells in your body multiply? (N = 87).

Tabela 2: Odgovori učencev na vprašanje: Čemu se celice v tvojem telesu delijo? (N = 87).

Answer	Number of answers (%)
Correct	10.1
Semi-correct	2.0
Incorrect	15.2
No answer	72.7

education. It is hard to expect that students with a limited understanding of the basic concepts could develop an understanding of the more advanced topics (Saka et al. 2006).

When you cut your skin it eventually heals. Describe the process of healing.

This question was only answered by the 15 year-olds. More than half (53.5%) did not even attempt to answer, while a quarter (25.3%) answered incorrectly. In semi-correct answers (12.1%) students did not explicitly link cell division with wound healing, but they noted, for instance:

“The skin is regenerating and with that the wound cicatrizes.” “The skin cicatrizes.” “The cells are cicatrizing over the wound.”

A correct answer was given only by 9.1% of students, in terms of “the skin regenerates – skin cells multiply.” We can therefore see that only a small part of students who finished elementary school (15 year-olds) have at least a basic understanding of wound healing, even though they encounter it almost daily. This is linked to the lack of fundamental knowledge, as some of the students don’t know that all organisms are made of cells (Fig. 1 and Fig. 3). Even greater is the proportion of students who don’t know that cells divide in all organisms (Fig. 2 and Fig. 3). The finding that students don’t have sufficient fundamental knowledge of the cell, which is an obstacle for further work, was also established by Banet and Ayuso (2000).

Conclusions

All groups of students in our sample, regardless of the level of education, have some surprising misconceptions about individual living beings. The worrisome fact is that too many students do not possess basic biological knowledge (as is the concept of cellular structure of all living beings) when they finish elementary school. This is of special concern since many of these students will never learn biology again in their further education.

We accepted the first hypothesis saying that the knowledge and understanding of basic concepts concerning the cell and cell division increases with the age of students in our sample, since we found that the results of 21 year-olds were significantly better than the results of 13 year-olds and

15 year-olds. However, a too large percentage of students even at the university level failed to make a complete shift to a better understanding of the cell. This is particularly worrisome because those were third-year pre-service biology teachers, i.e. people who will, in a few years, teach this subject in elementary or secondary school.

We also accepted the second hypothesis saying that students finishing general elementary education do not possess useful knowledge regarding the cell and cell division, as stated in our national curriculum. We found that students finishing elementary school in Slovenia (15 year-olds) do not understand the basic mechanism of wound healing. This is linked to a lack of meaningful fundamental knowledge – a significant number of students don’t know that all organisms are made of cells or that the cells divide in all organisms.

In Slovenia, we are now in the running-in period of the new curriculum for the elementary school level, and we are looking for solutions that would enable the general population to understand the basics of biology. Teachers are faced with the problem of: (1) how to present biological content in the most comprehensive manner; and (2) how to provide what students will need for everyday life, as well as a solid foundation for any further education.

We believe that a biology program for elementary schools should originate from the direct experience of students and, where possible, include useful knowledge for everyday life. This would make it more interesting for the students. Teachers should also be aware of the misconceptions that are widespread among students.

The results of our survey will serve as the basis to build a consistent sequence of teaching this topic. This will allow students to learn with understanding, which is an essential foundation for the acquisition of useful knowledge.

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