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CZECH HIGH SCHOOL STUDENTS' MISCONCEPTIONS ABOUT BASIC GENETIC CONCEPTS: PRELIMINARY RESULTS

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Abstract. *The revelation of misconceptions contributes to better education, especially when that information is described in a specific field of science. Additionally, genetics is one of very problematic topics, and misconceptions appear there frequently as there are difficult interconnections among them. The main aim of the study was to explore high school students´ misconceptions about basic genetics concepts. Moreover the influence of gender was also examined. Respondents were 102 Czech high school students of two high schools. Research tool was test containing 15 two tier questions concerning about basic genetics concepts like chromosome, DNA, allele and gene. Reliability was determined with the use of Cronbach's alpha coefficient. The result of Kolmogor-Smirnov test allowed to use parametric statistical methods. The data were analysed by the using of descriptive statistical methods (mean score) and inferential statistical methods (ANOVA). Concept 'DNA' was determined as the most problematic one for students, contrarily concept 'allele' was the simplest one. It was found that high school students do not understand selected basic genetic concepts. In addition, students do not interconnect genetic concepts within one complex system of knowledge, they also do not realise structure and hierarchy of these concepts.*

Key words: *basic genetics concepts, misconceptions, genetics learning, high school students*.

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Introduction

There are existing many researches regarding children's, pupils' or students' wrong ideas in different science areas. The reason for the researchers' focus on children's ideas is that these ideas are often different from ideas of scientists. This study deals with students' ideas about basic genetic concepts. Genetics is a difficult and abstract topic, therefore the misconceptions appear more often than in other fields of science (Cimer, 2012) and children, pupils and also students have got problems with the understanding of abstract topics (e.g. Kacovsky, 2015). Moreover, different levels of biological organisation of genetic processes contribute to creation of misconceptions. Another reason for this study is current rise of the importance of genetics. Genetics has become part of the central theme in biology as it relates to evolution and traits of populations of organisms. Successively, genetics has been appearing in human lives more frequently than ever before. People can meet with genetic topics through the mass media in a popular way (popular crime series) or in a more serious way (newspapers, documentaries). Information about genetically modified organisms, fingerprinting, genetic diseases, cloning, gene therapy is widespread among us. Additionally, genetics started to be an important factor in human health and reproduction. This creates a requirement for higher level of genetic education than before. Schools have to deal with this progress in education process and in curriculum. Genetics is one of the most difficult topics both for students to learn and teachers to teach (Finley, Stewart & Yarroch, 1982; Bahar, Johnstone & Hansell, 1999).

Theoretical Framework

Misconceptions

In the studies regarding similar problematic like I in this study, it is possible to see the using of different concepts, like alternative conceptions, misconceptions, preconception, wrong ideas and others. The concept misconception was preferred before concept preconception in this study. The reason is that preconception means ideas held before instruction (Clement, Brown & Zietsman, 1989) and in our study all questions contain kinds of information, which were known by students. Misconceptions are typically strongly resilient, and traditional teaching methods have difficulty eliminating them. Moreover, misconceptions frequently remain preserved after instruction (Eryilmaz, 2002). The genetics brings among subjects, which are in many considerations considered as abstract for students. Students have got problems with the imagination of different genetic concepts and processes connected with this biological discipline. The similar explanation was stated in the study of Duncan & Reiser (2007), they quoted students have difficulties in the invisibility and inaccessibility of genetics concepts. Next, the genetics included complicated structure. Genetics involved multiple biological organization levels—genes, proteins, cells, tissues, organs, etc. The similar findings were presented in other studies (e.g. Hasni, Roy & Dumais, 2016). Lewis, Leach & Wood-Robinson (2000) specify misconceptions in genetics: students are not able to interconnect genetic concepts belonging to different level of biological organisations, thus disorganized mind maps appear. This leads to specific misconceptions and misunderstandings connected with genetics.

Genetics in Czech High School

For the first time, learners meet with genetics in formal education at primary schools in biology lessons, where only basic information connected with this issue is presented in section Biology and Genetics (specifically in two subsections: (1) sexual and asexual reproduction and heredity, (2) examples of heredity from everyday life and examples of influence of environment). Thereafter, genetics is included in curriculum according to the specialization of particular high school. Technical or vocational schools incorporate genetics just marginally. Genetics is taught in detail at high schools and at nursing schools, where usually entire school year is focused on this topic (mostly the penultimate or last year of this level of education). The range of curriculum connected with genetics is given by subsequent areas: (1) molecular and cellular basis of heredity, (2) heredity and variability, (3) human genetics and (4) population genetics.

Research Conducted at High Schools

Studies detected misconceptions among high school students vary in their purpose and methods. Lewis, Leach & Wood-Robinson (2000) concentrated on basic genetic concepts and their interconnections. Researchers discovered that a common misconception of high school students is that cells with different function have different genetic information. Likewise, students did not distinguish between body cell and sexual cell (gamete). Authors emphasized that knowledge of students was inconsistent and lacked interconnections. Venville & Treagust (1998) investigated if high school students used modern ways of understanding the concept "gene". Authors of this study identified students' obsolete and passive way of understanding the concept "gene". Moreover, students tended to solve all practical questions by using Mendelian genetics in spite of its unsuitability. Shaw et al. (2008) learned that students connected one trait of organism with one gene. They have problems with explanation of dominance and recessiveness, hierarchy of DNA and definitions of gene, DNA and chromosome. Cisterna, Williams & Merritt (2013) explored pupils' ideas about cells and inheritance and describe patterns of understanding these topics. Pupils tended to struggle in distinguishing genes, chromosomes, and DNA and had some difficulties connecting the cell division process with the inheritance of genetic material. Kılıç a Sağlam (2014) ascertained the effect of reasoning ability and learning approaches on students´ understanding of genetics concepts. Authors used two-tier genetic concept test. Significant influence of reasoning ability and learning approach was revealed. Kibuka & Sebitosi (2007) focused on understanding genetics and inheritance in rural schools. Results showed insufficient distinguishing between concepts gene and chromosome. Also, understanding to concept inheritance and Mendelian genetics were confusing. Moreover, students had conflict between traditional reasoning connected with local habits and scientific reasoning. Other author Kim (2010) used questionnaire with open-ended questions to ascertain

understanding to basic genetics concepts. Results revealed erroneous understanding of interconnection of basic genetic concepts. This author alerts on misleading and incorrect presentation of many genetic concepts. Topcu & Sahin-Pekmez (2009) revealed high school students' difficulties in learning genetic concepts. Both quantitative and qualitative research approaches were used in their study. Survey method was used to explore the students' difficulties in conceptual and procedural level. An open-ended questionnaire was conducted to find out students' difficulties in learning genetics.

Moreover, basic interpretive qualitative research approach was used in the present study. Parallel with this approach, a semi-structured interview was conducted to find out the students' difficulties comprehensively. Authors determined that major difficulties in learning genetics were the function of cell and chromosome concepts. The difficulties related to teaching methods, textbooks, and mathematical expressions were other difficulties determined in this study. Misconceptions in genetics are explored among university students too. Results of these studies are similar to results of studies conducted in high schools mentioned above (eg. Boujemaa et al., 2010; Smith & Knight, 2012; Karagöz & Çakir, 2011).

According to the results of current researches, misconceptions in genetics are frequent. In spite of research that was conducted, there are plenty of uncovered problems which need more systematic and in-depth research. Researchers should inquire about what students really do know about basic genetic concepts, if they are able to interconnect these concepts, and what influences misconceptions to appear. Some studies focused on basic concepts and their interconnections, but studies which attempted to identify influences affecting misconceptions are rare. The aim of this research was to explore high school students´ misconceptions about basic genetic concepts. Moreover, influence of gender was studied. On the base of the aim, research questions were established.

1. What kinds of misconceptions have high school students about basic genetic concepts (DNA, gene, allele, and chromosome)?
2. Are misconceptions in genetics influenced by gender?

Methodology of Research

This research was conducted using test. Questions used in the test were developed by us followed the Czech high school curriculum. The data was obtained from Czech high school students. The first intention was to choose the schools and respondents randomly. But the majority of selected principals refused the realization of research, so the respondents are selected by conventional sampling. The conventional sampling is useful for preliminary studies of an issue, to identify what may be the key features to investigate in more details or to test the effectiveness of the survey procedure and survey instruments (Newby, 2014). On the request of school principals, their location and name are anonymous. The respondents were assured that their responses would only be used for research purpose and would not affect their final exam scores. The test was administered in a group format among respondents during the June of 2015.

Respondents

The sample size consisted of high school students (102 students chosen from 2 high schools). This sample size is appropriate for the pilot studies. In many studies it was possible to find minimal sample size (e.g. Johanson & Brooks, 2009; Youssef, 2011). Moreover, this research does not ascertain only general characteristics of using instrument (in this case test), but also the detailed analysis of questions in the test. The participation of students on the research was voluntary, so this fact led to relatively low amount of respondents in entire research. The sample size is adequate for the research. The observed power was calculated for every value of ANOVA. Its value was between 0.72 and 0.81, it signalized the sufficient sample for the study and also the availability of the using ANOVA (for the detailed explanation see MacCallum, Browne & Sugawara, 1996; O Keefe, 2007 and others). Before testing, all students attended biology lessons discussing genetics. All students attended last grade (4th) of high school in the time of research, their age was between 18 – 19 years. Girls accounted for 67 % and boys 35 % of the sample size.

Research Tool

Research tool consisted of two parts. Firstly, demographic items were given (gender, belief and achievement in biology). Secondly, 15 two-test (with 4 possibilities, only one correct answer) concerning basic genetic concepts followed. The studies regarding using of two-tier tests were inspiration for the creation of research tool (e.g. Svandova, 2014; Treagust, 1988). The second part of the research tool was divided into four specific dimensions relating to one basic genetic concept. The first dimension "DNA" contained four questions, and this dimension is illustrated by question number 1 ("How genetic information is transmitted from DNA?"). The second dimension "allele" included three questions, for instance question number 5 ("Peter was born with problematic skin. He is albino. Albinism is recessive characteristic. We use "A" for dominant gene (allele) and "a" for recessive allele. Albinism has heredity with complete dominance. Can you determine Peters' phenotype?"). "Gene" was the basic concept in the third dimension covered by 4 questions. An example of the third dimension is question number 8 ("How gene realizes its genetic information to particular trait?"). Last dimension focused on concept "Chromosome", and there were 4 questions included. For instance, question number 15 belongs to this dimension ("Which statement about heredity of sex is correct?"). Questions followed the Czech high school curriculum, all required information should be known by students. All questions were discussed with the high school biology teacher. They suggested only stylistic revision of the questions, their final decision was that the test is appropriate for the high school students. The test was administered by research authors, and the respondents were assured about anonymity. Completing of this test took approximately 30 minutes.

Data Analysis

Gender was considered an independent variable. Score obtained in the second part of the research tool was established as a dependent variable. Collected data were converted into numeric and electronic form. Each incorrect answer was marked with 0 and each correct answer was marked with 1. This characteristic of data allowed to calculate average score of the test. Students with all correct answers had an average score of 1 and students with all incorrect answers had score 0.

Reliability was determined with the use of Cronbach's alpha coefficient ($\alpha = 0.68$). This score is sufficient for the research tool, which was originally created by authors and was tested in the pilot research. According to Nunnally (1978) if the research tool was first time used, the acceptable value of alpha is 0.50 – 0.60. Sekaran (1992) set the minimum acceptable reliability coefficient level at 0.60. As a general rule of thumb (Shoukri, and Edge 1996), a reliability coefficient (r) is considered excellent if r is larger than 0.75, good - if r is between 0.40 and 0.75, and poor if r is less than 0.40. Normality of data was determined with Kolmogor-Smirnov test ($d = 0.10$, $p > 0.20$). Result of Kolmogor-Smirnov test allowed to apply the parametric methods. The descriptive methods (mean) and the inferential methods (ANOVA) were used.

Results of Research

Overall Results and Results According to the Independent Variables

Average score of the test was 0.43 (SD = 0.15). Influence of the independent variables was surveyed. Girls obtained slightly higher average score ($\overline{x} = 0.44$; SD = 0.02) in comparison with boys ($\overline{x} = 0.40$; SD = 0.02). Results are illustrated in Figure 1. There were no statistically significant differences for the independent variable "gender" ($F = 1.60$, $p = 0.21$).

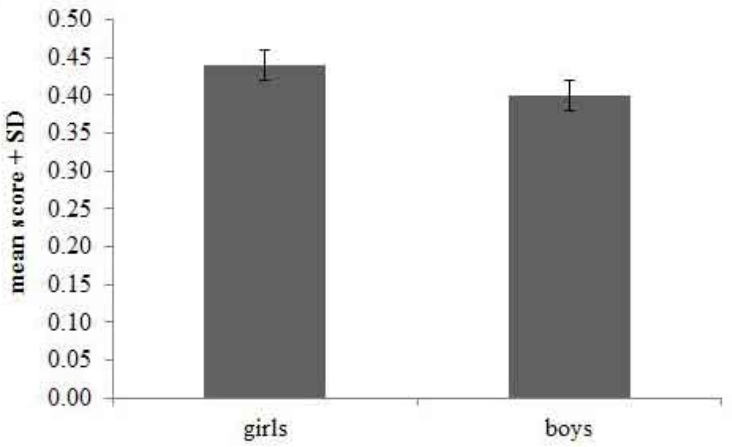

Figure 1: Influence of gender according to overall average score.

Results According to Dimensions

Average score was determined in four dimensions of the test. The highest score was determined in dimension "Allele" ($\overline{X}$ = 0.57, SD = 0.83). The most difficult dimension for students was "DNA" ($\overline{X}$ = 0.36, SD = 0.22). Table 1 summarizes average score and standard deviation for these dimensions.

Table 1. Mean score and standard deviation according to dimensions.

Dimensions	Mean score	SD
DNA	0.36	0.22
Allele	0.57	0.83
Gene	0.43	0.23
Chromosome	0.40	0.22

The most problematic dimension was "DNA" ($\overline{X}$ =0.36, SD = 0.22). In this dimension were several misconceptions revealed. Students had problems with DNA structure and they did not know what structural sections of double helix are. Two thirds of respondents claimed that DNA is created by amino acids. One third of students did not know function of mRNA, and their knowledge about transmission of genetic information from DNA to trait was confusing. One third of students stated that one gene is created by one molecule of DNA, and one quarter of students claimed that one molecule of DNA creates one chromatid of chromosome.

Variable "gender" was not identified to be statistically significant variable in this dimension (F = 0.28, p = 0.59). Boys obtained a slightly lower score ($\overline{X}$ = 0.34) than girls ($\overline{X}$ = 0.36).

Another problematic dimension was "Chromosome" ($\overline{X}$ =0.40, SD = 0.22). One fifth of students indicated that the number of chromosomes is similar for all species and the numbers of genes vary among individuals within particular species. More than one third of students supposed that all 23 pairs of chromosome are homologue, and they did not see any differences between somatic and sex chromosome. Further 36 % of students assumed that sex chromosomes are only in gametes. Another quite common misconception was that there are more women in population because there are more chromosomes X in population than chromosomes Y. The independent variable "gender" (F = 0.03, p = 0.86) was not detected to be statistically significant in this dimension, boys and girls achieved identical score x = 0.40.

The dimension "Gene" was also difficult for students ($\overline{X}$ = 0.43, SD = 0.23). In this dimension 29 % of students anticipated that one gene creates one chromatid of chromosome, and this chromatid creates one trait. Presumption of 35 % of respondents was that gene is created by the sequence of alleles. One fifth of students had problems with concept locus. Further one third of students assumed that one gene is responsible for one trait. The independent

variable "gender" was analysed to be statistically significant variable in dimension 'Gene' ($F = 7.57$, $p < 0.05$). In this dimension boys obtained average score $\overline{X} = 0.34$ and girls obtained average score $\overline{X} = 0.47$

Dimension "Allele" was the simplest one for students ($\overline{X} = 0.57$, $SD = 0.83$). Explanation of dominance and recessiveness of alleles was for most students easy. Almost half of students (44 %) presumed that two alleles are connected with one gene, but actually one, two or more alleles connected with one gene appear within population. Gender was not determined to be statistically significant in dimension "Allele", boys and girls gained average score $\overline{X} = 0.57$.

Discussion

First research question was: "What kinds of misconceptions have high school students about basic genetic concepts (DNA, gene, allele, and chromosome)?" The most difficult for students was concept DNA. Students reached one third of points in average. Students had problems with describing the structure of DNA; similar results published Shaw et al. (2008). Other problematic areas were function of mRNA and transiting of genetic information from DNA to trait, or relation and interconnection of concept DNA with other concepts gene, chromatid and chromosome.

Another concept was chromosome. This concept was for students easier than concept DNA and gene, nonetheless average score was slightly lower than midpoint. The concept of chromosome was connected with another serious misunderstanding, which appeared in the research. Students claimed that the number of chromosomes is similar for all species and the number of genes vary merely among individuals within particular species. Also students were not able to distinguish between somatic and sex chromosomes. Sex chromosomes were located by students just in gametes. These findings match those observed in earlier studies. Lewis, Leach & Wood-Robinson (2000) explored that students have problems with distinguishing sex and somatic cell. Also, Smith & Knight (2012) came with finding that students are convinced about dissimilar content of genes in body cells.

The third investigated concept was gene. This concept was the second easiest one, however, in average students did not reach midpoint of score. Students had problems with concept locus, which is closely related to concept gene. A prominent misconception was that one gene is responsible for one trait. There are similarities in research of Tsui & Treagust (2010) and Shaw et al. (2008), who alerted in their studies to conspicuous preference of Mendelian genetics and its rules. Students had again problems with interconnecting this concept with other concepts, specifically with chromatid and chromosome. Karagöz & Çakir (2011) presented similar findings, which indicated confusing understanding of whole concept gene.

The concept of allele was the simplest one for students. Nevertheless, the average score was not higher than two thirds of total score. The understanding of concept allele was not so confusing as students could distinguish between dominancy and resistivity of allele. However, these results differ from Shaw et al. (2008). Explanation of dominance and recessiveness of alleles was for most students easy, but some misconceptions were uncovered. Students had problems with interconnection of this concept with other examined concepts.

Final results confirmed an absence of interconnections among genetic concepts; these findings were ascertained by other authors (Tsui & Treagust, 2010). Results of this study revealed that recessiveness and dominance of alleles is not problematic, however contradictory results were discovered by Shaw et al. (2008). Understanding of the most fundamental concept gene was problematic in many researches (Shaw et al., 2008; Tsui & Treagust, 2010; Karagöz & Çakir, 2011; Smith & Knight, 2012).

The results indicated that Czech high school students had several difficulties in learning genetics. One of the biggest problems students have, they did generally not conceptualize the genetic concepts. Instead of this, they generally memorized these concepts. They did not have problems to define the genetic concepts. But, by the questions regarding function of these genetics concepts, and their reason of answer, they mostly failed. In addition to the functions of genetics concepts, students had difficulty in the size relationships among genetic concepts. From this point it is important to improve genetic literacy of teachers, because without it, the knowledge about genetics will be on still equal level and also the misconceptions in this field of study will be still presenting. This problem was presented in the study of Cebesoy & Oztekin (2016).

The second research question was: "How does gender influence misconception in genetics?" This independent variable was not statistically significant in overall results. Correspondingly, differences according to the independent variable gender were not detected in dimensions DNA, chromosome and allele. In the contrary, difference was detected only in dimension gender, where girls obtained higher score than boys. Our results are in the concordance with Kessler, Collier & Halbert (2007), where gender had not got influence on the knowledge about genetics. And

as it was found out in one dimension girls achieved better score in comparison with boys, this fact is possible to find in the study of Molster et al. (2009), they found out better knowledge at women in comparison with men. Results regarding gender were only additional. Further research in this domain will focus on the influence of the different variables. However, here are some cues, the score was nearly identical, because in this problematic is the clash of abstract and also concrete facts. Maybe, this is caused by the fact that girls have more positive attitudes toward biology in comparison with boys and it manifests itself by better knowledge. The next reason could be that in many schools in the Czech Republic the traditional style of learning process focused on memorizing with minimum of modern elements is still persisting. The modern elements could make the learning process more interesting and more meaningful.

To summarize these findings, results proved that achievement in biology is essential during the process of dispelling misconceptions. Gender was not detected as noticeable factor influencing misconceptions. Concerning the preference of science subjects by boys and humanities by girls, this does not change formation of misconceptions.

Conclusions

From results of this research emerge high school students´ misunderstanding of basic genetic concepts and poor interconnecting genetic concepts to one linked system of knowledge. Teachers of science subjects should be aware about this situation. They should teach genetic concepts in interconnections and with focus on deep understanding instead of simple memorizing. Also, universities should prepare prospective science teachers for this situation. High quality materials should be created for science lessons. For example, some PC programmes and games, work-sheets etc.

Consequently, in-depth research on this topic needs to be undertaken to have a deeper understanding of comprehension of genetic concepts. There are still many questions which need to be answered. Further work is required to establish misconceptions connected with interconnection of genetic concepts. Moreover, this research was focused on high school students and there are still many unanswered questions about comprehension of basic genetic concepts among primary school pupils or university students. Also, the effect of some new independent variables should be enquired. For instance, the implementation of modern technologies can be one of the influencing variables.

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