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EXTENDED ESSAY
BIOLOGY

Inheritance of the colour of eyes in humans and the distribution of this characteristic in a given population.

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Abstract

The aim of this investigation is to determine the distribution of the colour of eyes in a given population of students of VI Liceum Ogólnokształcące in Kielce (16-19 years old) and to examine how this characteristic is inherited. To achieve this goal, data including iris colour of 100 individuals and their closest relatives were collected. The colour of eyes of each individual was assessed in the same room with the same artificial light turned on. Information about eye colour of individuals' family was gained through investigated people. The stated hypothesis said that there would be the greatest percentage of brown-eyed people, smaller amount of blue-eyed ones and the smallest number of individuals with green iris. It was based on Mendel's idea of inheritance of 2 of 3 known genes responsible for colour of eyes – bey 2 and gey; the third gene, bey 1 could not be used as its way of action is not well-known yet. The results do not completely coincide with hypothesis.

The obtained distribution shows that in the chosen population, percentage of people with brown and blue eyes is equal (37%) and number of green-eyed people is significantly smaller (23%). This inconsistency can be a result of the fact that Europe, especially the eastern part, is the region of the world with the greatest variety of colour of both eyes and hair. What is more, among investigated population there were individuals, who have green or brown colour of iris, whereas their both parents have blue eyes. This fact suggests that more than so far discovered genes influence the inheritance of the colour of human eyes.

Word count: 268

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1. Research question

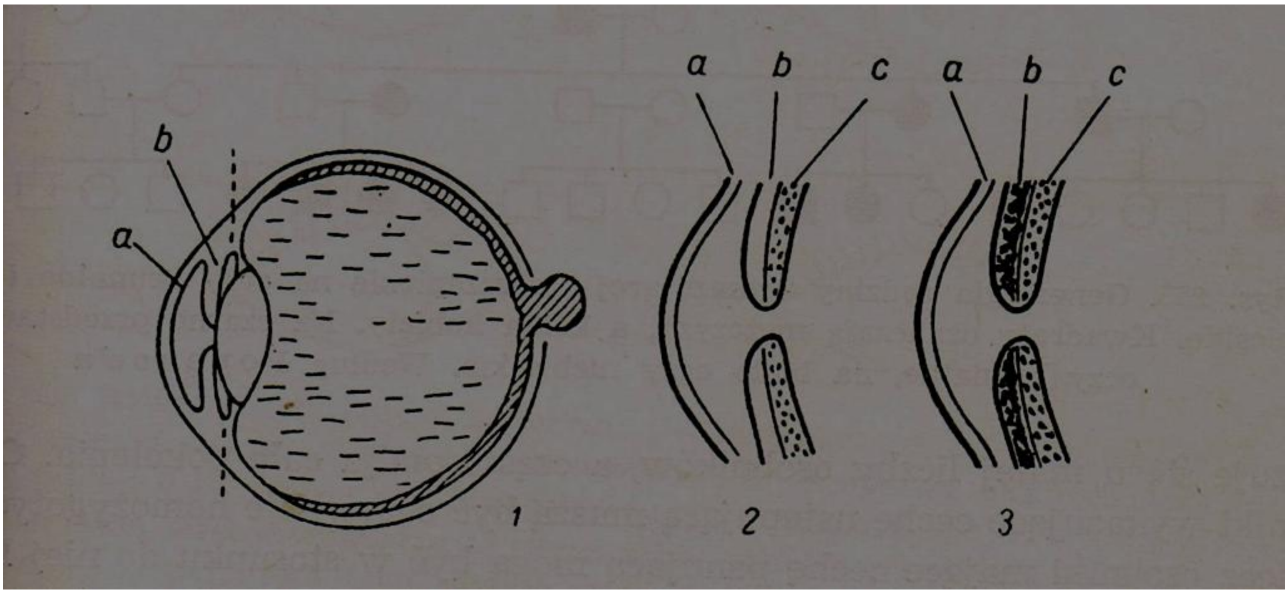
How does the colour of human eyes is inherited and what is the distribution of this feature in the population of students of VI Liceum Ogólnokształcące in Kielce?

2. Introduction

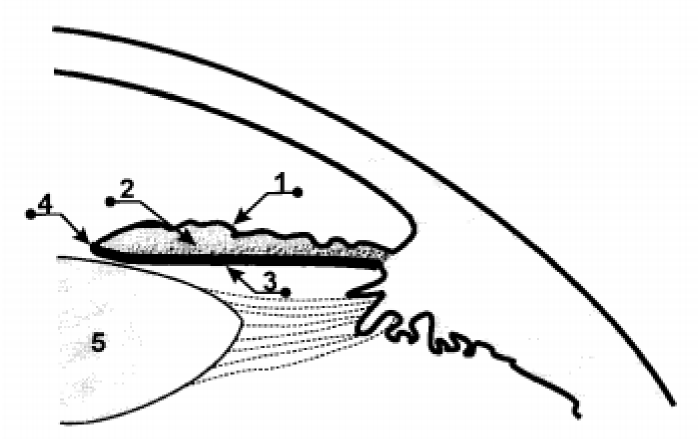
My first contact with genetics was in Junior High School. The student book contained basic information about structure of DNA double helix, chromosomes and allels. It was also the first time, when I had an opportunity to learn something more about inheritance of features like colour of flowers or seeds in *Pisum sativum.* On further lessons I was taught about inheritance of blood type or the ability to roll the tongue in humans. There was nothing about colour of the human iris. The need of gaining this knowledge led me to trials of searching it in available in this time sources like the internet and books. It turned out that my general knowledge of the genetics was too limited, thus blocking the complete understanding of this topic. That is how my fascination started. Coming to IB Diploma Programme, I hoped these information would be the part of biology course on higher level, but there was only a short reference to it as a polygenic feature. Observation can lead us to the simple conclusion that inheritance of this feature must be much more complicated than Mendelian one. Occurrence of *Heterochromia iridum* (difference in coloration of the iris), both complete and sectoral, is the clearest evidence. The second, equally important reason, why I decided to devote my extended essay to the topic of inheritance of the colour of the human iris is my interest in ophthalmology as a certain part of medicine.

2.1. Iris – part of the eye

Iris is the forepart of the choroidea of the eye. This thin coloured diaphragm is situated between the cornea and the crystalline lens. It comprises mostly of connective tissue and smooth muscle fibres. “The human iris begins to form during the third month of gestation. The structure is complete by the eighth month of gestation, but pigmentation continues into the frst year after birth” (Muron and Pospísil 2000). There are three parts of the iris, which can be distinguished: endothelium, stroma and epithelium. The opening of the iris is called pupil. Contraction and expansion of the iris regulates the size of the pupil thus controlling the amount of light entering the further parts of the eye. It is possible because of the action of the pupillary sphincter muscle and dilator muscle. The iris also divides the anterior segment of the eye into two chambers: the anterior chamber, which extends from the cornea to the iris and the posterior chamber, which extends from the iris to the lens.



Picture 1: Cross-section of the human eye. 1 a – cornea, 1 b – iris, 2 a – cornea, 2 b – front part of iris without pigment (unstained), 2 c – back blue part of iris, 3 a – cornea, 3 b – front part of iris containing pigment, 3 c – back blue part of iris (Malinowski, 1974)



Picture 2: Section through the human iris (1-anterior layer, 2-stroma, 3-posterior layer, 4-pigment frill, 5-lens) (Muron and Pospísil 2000)

The colour of the iris depends on the amount and distribution of the pigment called melanin. “At the cellular level, variable iris color in healthy humans is the result of the differential deposition of melanin pigment granules within a fixed number of stromal melanocytes in the iris. The density of granules appears to reach genetically determined levels by early childhood and usually remains constant throughout later life, although a small minority of individuals exhibit changes in color during later stages of life.”(Frudakis, Thomas, and others 2003).

2.2. Key terms

- “Melanin – any of a group of naturally occurring dark pigments composed of granules of highly irregular polymers that usually contain nitrogen or sulfur atoms, especially the pigment found in skin, hair, fur, and feathers.” (“The American Heritage Stedman's Medical Dictionary” 2002)

  “Eumelanin (brown/black melanins) and pheomelanin (red/yellow melanins) are produced by melanocytes. The Melanocortin-1 Receptor Gene is a regulator of eumelanin production and is located on chromosome (MCIR) 16q24.3. Point mutations in the MCIR gene will affect melanogenesis. The presence of point mutations in the MCIR gene alleles is a common feature in light skinned and blue/green eyed people"(Frudakis, Thomas, and others 2003)

- "Polygenic inheritance – it involves two or more genes influencing the expression of one trait. With two or more allelic pairs found at different loci, the number of possible genotypes is greatly increased."(Damon, McGonnegal, and others 2007)

2.3. The colour of the iris as a polygenic trait

"The transmission genetics for pigmentation traits in humans and various model systems suggests that variable pigmentation is a function of multiple heritable factors whose interactions appear to be quite complex" (Frudakis, Thomas, and others 2003). There are 3 known genes, which control the inheritance of the colour of the eyes. The bey 1 gene, which is located on chromosome 15 is the central brown gene. On the same chromosome there is also the bey 2 gene, which determines the occurrence of brown and blue colour of the iris (brown dominant over blue). The third one, the gey gene, which determines green and blue colour (green dominant over blue) is located on chromosome pair 19. Generally, the brown allele is dominant over both blue and green ones. For example when an individual has a brown allele on chromosome 15, and other alleles are blue or green, the phenotype of this person will be brown. For occurrence of green eyes, only one green allele on chromosome 19 and other blue alleles are required. A blue eyed person would have all four blue alleles. This concept is the simplification – there is great variation in shadings of three mentioned above basic colours (brown, green, blue) and the occurrence of mutations is not taken into account.

2.4. Distribution of the characteristic – colour of the iris

Taking into consideration existence and relationships between three , so far known genes responsible for inheritance of the colour of the iris, dihybrid crosses can be created, which can become a basis for the pattern of distribution of this characteristic (examples of dihybrid crosses considering bey 2 and gey genes are present in the appendix). "Brown eyes are the most common eye color in the world with over 55% of the world's population having brown eyes.(…) Most people estimate that around 5-8% of the world's population has hazel colored eyes.(…) It's estimated that approximately 8% of the world's population has blue eyes. (…) It is estimated that only around 2% of the world's population has green colored eyes." ("Eye Color Guide" 2014). Both dihybrid crosses and found information can become the basis for the statement that the greatest percentage of the world population have brown eyes, there is considerably smaller percentage of people with blue eyes and the smallest number of people are the green-eyed ones.

2.5. *Heterochromia iridum*

"A difference in coloration in two structures or two parts of the same structure that are normally alike in color." ("The American Heritage Stedman's Medical Dictionary" 2002). The iris of a person with heterochromia have differently coloured patches or segments of the iris or (less frequently) the whole iris of one eye has a different colour in comparison to the iris of the second eye. As far as partial heterochromia is considered, two general types can be distinguished – sectoral and central. In central type of condition pupillary zone of the iris differs in colour from the ciliary zone, whereas sectoral heterochromia involves a differently coloured sector located independently on the centre of eye – the pupil. "In some cases, heterochromia iridis may be present from birth as part of a genetic disorder, such as Waardenburg syndrome, Sturge-Weber syndrome, or Parry-Romberg syndrome. In other cases, this condition may be acquired if eye color changes after an injury to the eye, due to damage to nerves near the eyes, or in response to an environmental exposure." ("Heterochromia iridis" 2011).

2.6. Albinism – disorder having an impact on the colour of eyes

According to The American Heritage Stedman's Medical Dictionary an albino is "a person or an animal lacking normal pigmentation, resulting in abnormally pale or white skin and hair and pink or blue eyes with a deep-red pupil." (2002). Even in a short, dictionary definition the influenced colour of eyes is mentioned. An albino has "the colored area in the center of the eye with little to no pigment to screen out stray light coming into the eye". "They have inherited altered genes that do not make the usual amounts of a pigment called melanin"(NOAH 2002). There are various types of albinism, that is why the colour of the iris can vary in particular examples of individuals showing an albinism. The colour described as pink or sometimes even red is the result of no melanin pigments in pigment frill (picture 2. 4) and due to this the blood supplying the eye and circulating through extremely small vessels in choroid is visible. However, " there are different types of albinism and the amount of pigment in the eyes varies. Although some individuals with albinism have reddish or violet eyes, most have blue eyes. Some have hazel or brown eyes."(NOAH 2002). "Overall, an estimated 1 in 20,000 people worldwide are born with oculocutaneous albinism. The condition affects people in many ethnic groups and geographical regions." ("Oculocutaneous albinism" 2014) – this information makes me take into consideration the fact that there is a possibility of occurrence of an individual with albinism in my investigated population as this condition is not linked with a particular ethnic group or geographical region.

3. Hypothesis

Taking into account information presented above, I can assume that the greatest percent of investigated people will have brown eyes, there will be much less number of blue-eyed people and the smallest percent will be in case of people with green eyes. Brown colour of the iris is the dominant feature over both blue and green ones. For the investigated population, which consists of 100 people the predicted distribution based on Punnett Squares considering two genes, which alleles can be crossed should be true. However, small number of individuals with *Heterochromia iridum* as well as with albinism can belong to investigated population. As far as inheritance of investigated characteristic is concerned, basing on the information considering dependencies between alleles of known genes responsible for eyes' colour inheritance there can be made an assumption that:

- both parents with brown eyes will have the greatest percentage of browned-eyed children, but both blue- and green-eyed can occur;
- both parents with green eyes will have the greatest percentage of green-eyed children, but also blue-eyed can occur;
- both parents with blue eyes will have only blue-eyed children; generally, when one of the parents have brown eyes, this colour is the most probable to occur in the offspring, but other colour can also occur; when one of the parents have blue eyes and the other one have green eyes, there are two equal possibilities of the eyes' colours of the offspring – green and blue;
- small number of individuals with *heterochromia iridum* can occur within the investigated population irrespective of the colour of eyes of the parents
- small number of individuals with albinism, and hence with reddish or violet eyes, can occur within the investigated population irrespective of the colour of eyes of the parents.

4. Method

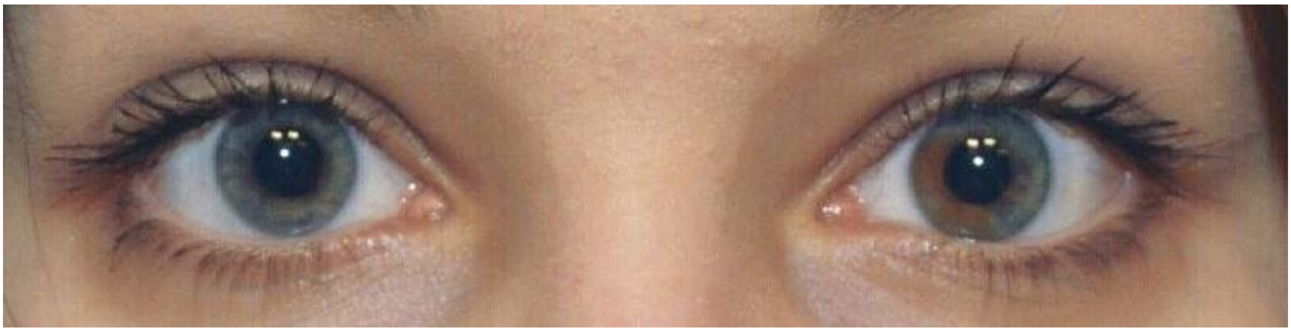
The chosen population is the population of students of VI LO in Kielce. A hundred of individuals were investigated and all them were in age between 17 (1^{st} class) and 19 (3^{rd} class). All of participants acceded to become the part of my investigation (signatures confirming the agreement – appendix). What is more, all of investigated individuals were born in Poland. The colour of eyes of students was assessed by me personally, always in the same light (in the classroom with turned on artificial lighting). Every individual was classified to one from 3 groups: having blue, green or brown eyes. It means that people with hazel eyes were classified as brown, individuals having grey eyes as blue ect. This generalization was crucial in order to have possibility to refer to inheritance connected with mentioned above 3 genes – bey 1, bey 2 and gey 1. In addition, central and small sectoral heterochromia were ignored while classification – the colour, which predominated was considered as general colour of eyes. Only clearly visible heterochromia (two colours clearly recognisable, visible “border” and contrast between colours) were classified as separate case. Additionally, the students were asked about colours of eyes of their closest relatives including parents and siblings. These data were assessed by the students themselves, not by me – this is the reason why they are not taken into consideration while distribution is determined.

5. Results

Table 1: Number of individuals having particular colours of eyes

Colour of eyes	Number of individuals
BROWN	37
GREEN	23
BLUE	37
HETEROCHROMIA*	3

*all 3 investigated individuals have heterochromia, which includes blue and brown colours



Picture 3: Example of individual, which was classified as a person with heterochromia

Graph 1: Percentage of individuals having particular colours of eyes

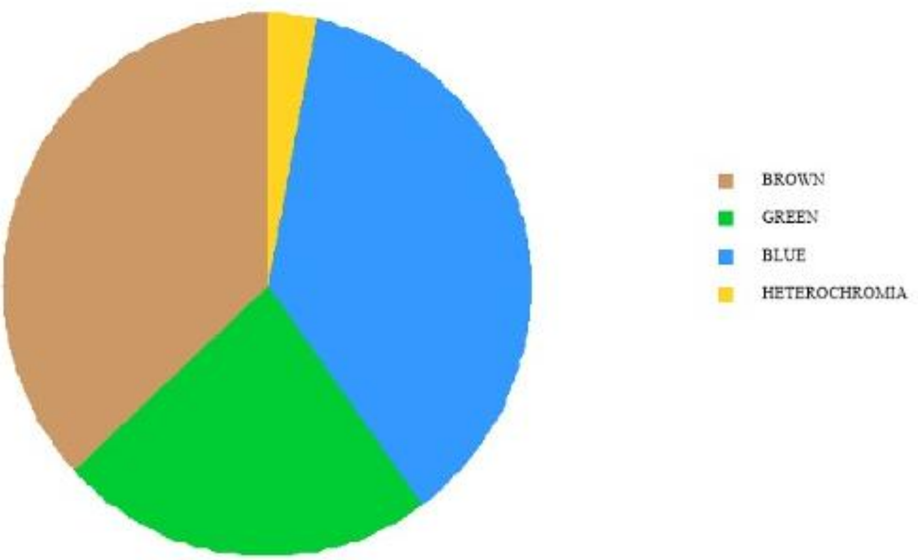
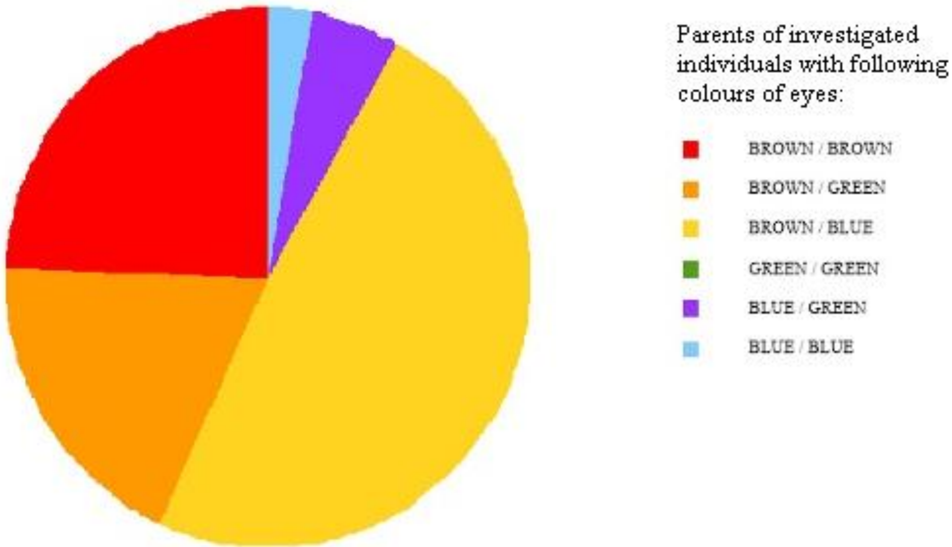


Table 2: Number of individuals having particular colour of eyes including information about colour of eyes of both parents

Colour of eyes	Parental colours of eyes	Number of individuals
BROWN	BROWN/BROWN	9
	BROWN/GREEN	7
	BROWN/BLUE	18
	GREEN/GREEN	0
	BLUE/GREEN	2
	BLUE/BLUE	1
GREEN	BROWN/BROWN	0
	BROWN/GREEN	6
	BROWN/BLUE	5
	GREEN/GREEN	1
	BLUE/GREEN	10
	BLUE/BLUE	1
BLUE	BROWN/BROWN	1
	BROWN/GREEN	5
	BROWN/BLUE	17
	GREEN/GREEN	0
	BLUE/GREEN	3
	BLUE/BLUE	11
HETEROCHROMIA	BLUE/BLUE	3

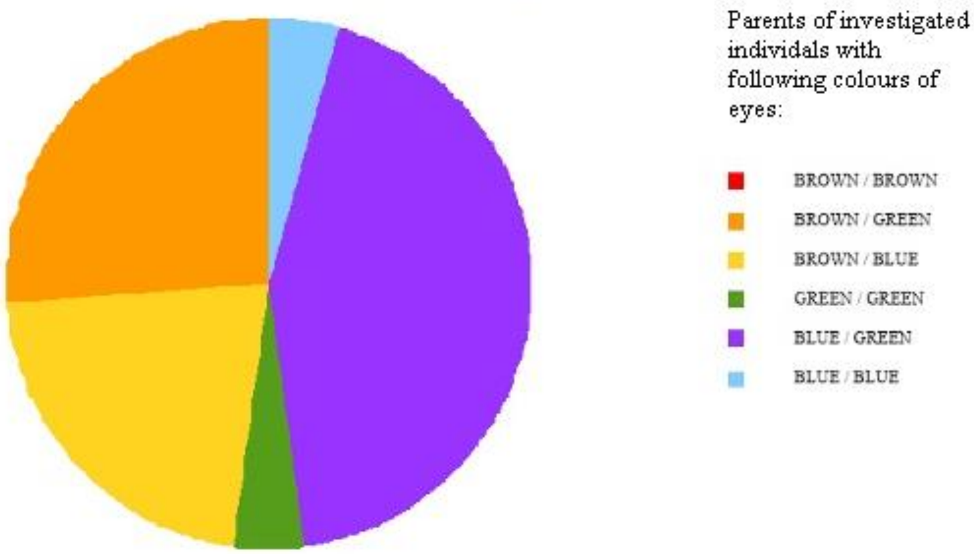
Graph 2 Percentage of individuals having brown eyes

division considering colour of eyes of both parents

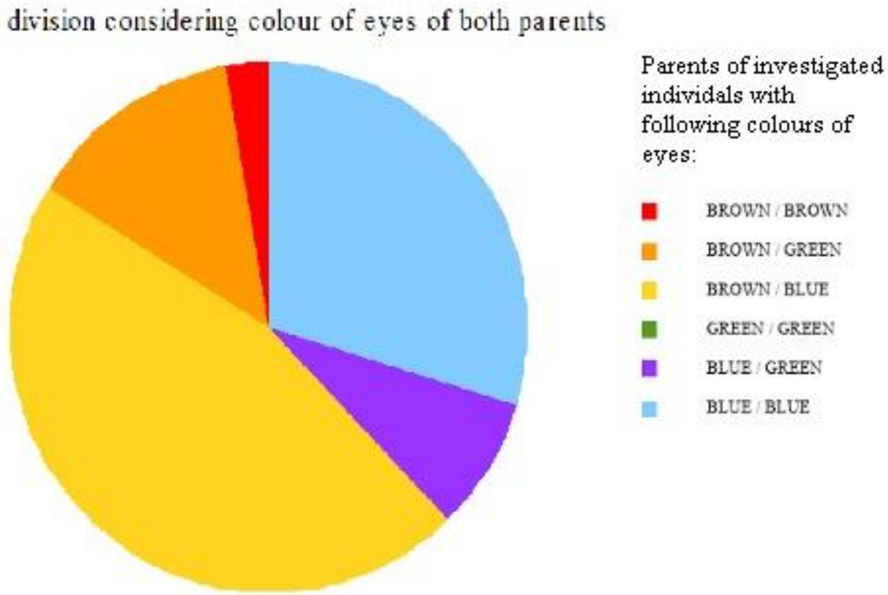


Graph 3 Percentage of individuals having green eyes

division considering colour of eyes of both parents



Graph 4 :Percentage of individuals having blue eyes



6. Processed data

To calculate percentage difference between quantity of individuals having particular colour of eyes the following formula will be used:

V_1 -number of individuals having first colour of iris

V_2-number of individuals having second colour of iris

$$\frac{|V1-V2|}{(V1+V2)/2}\times 100\%$$

for example:

calculating percentage difference between number of people having brown and green colour of iris

$$\frac{|37-23|}{(37+23)/2}\times 100\% = 47\%$$

To calculate a percentage of individuals, which parents have particular colours of eyes the following formula will be used:

X_1 – number of individuals having the same colour of eyes, which parents have particular colours of eyes

X – number of all individuals OR number of all individuals having the same colour of eyes

$$\frac{X1}{X}\times 100\%$$

for example:

calculating a percentage of individuals having brown eyes, which both parents have brown eyes

$$\frac{9}{37}\times 100\% = 24\%$$

$$\frac{9}{100}\times 100\% = 9\%$$

It means individuals having brown eyes, which both parents have brown eyes represent 24% of all individuals having brown eyes and 9% of all investigated individuals.

Table 3: Percentage difference between number of people having particular colours of eyes

Percentage difference [%] between number of people having:				
	BROWN	GREEN	BLUE	HETEROCHROMIA
BROWN	-	47	0	170
GREEN		-	47	154
BLUE			-	170
HETEROCHROMIA				-

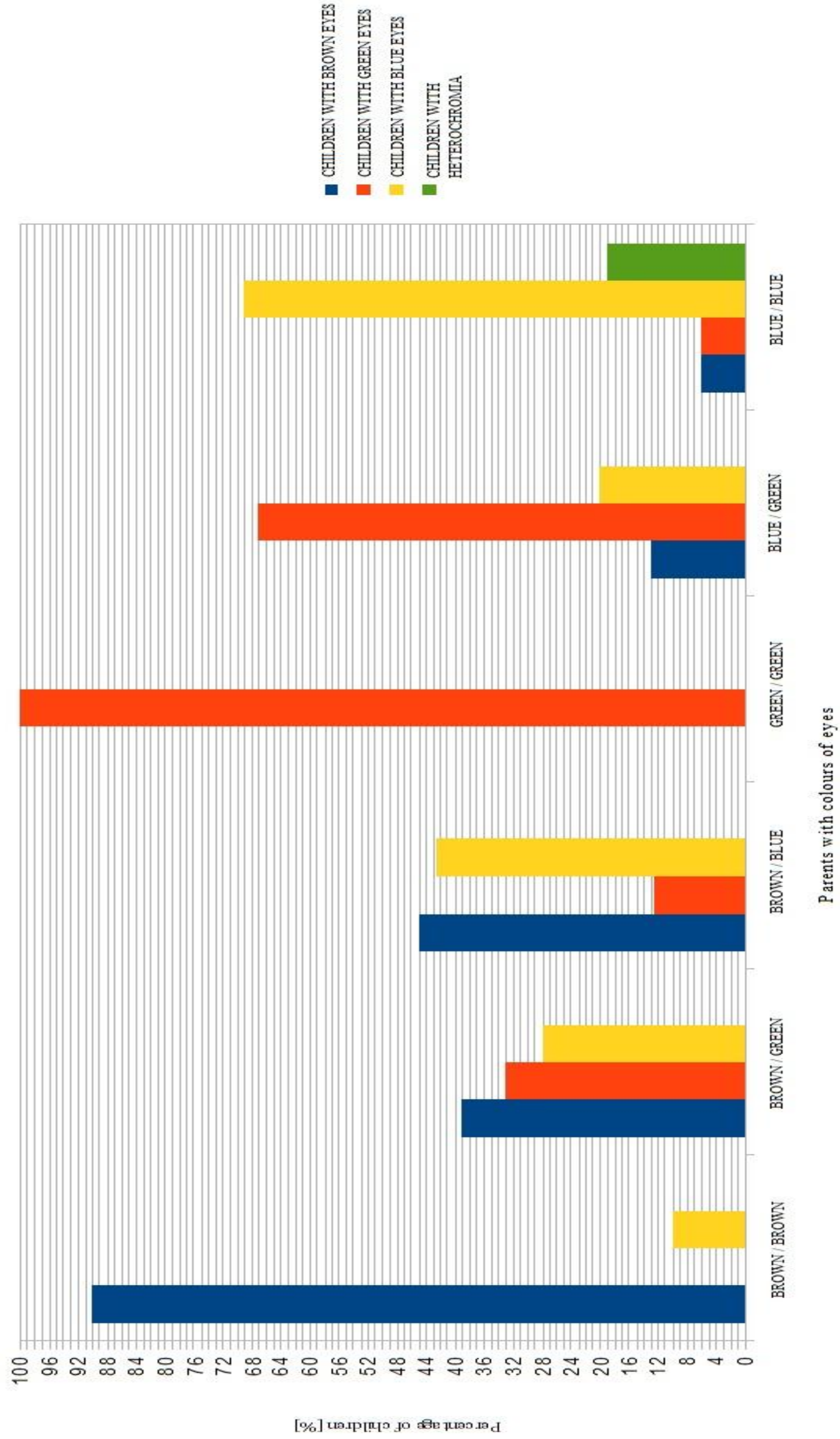
Table 4: Percentage of individuals, whose parents have particular colours of eyes

Colour of eyes of individual	Parental colours of eyes	Number of individuals	Percentage of all individuals having the same colour of eyes [%]	Percentage of all investigated individuals [%]
BROWN	BROWN/BROWN	9	24	9
	BROWN/GREEN	7	19	7
	BROWN/BLUE	18	49	18
	GREEN/GREEN	0	0	0
	BLUE/GREEN	2	5	2
	BLUE/BLUE	1	3	1
GREEN	BROWN/BROWN	0	0	0
	BROWN/GREEN	6	26	6
	BROWN/BLUE	5	22	5
	GREEN/GREEN	1	4	1
	BLUE/GREEN	10	44	10
	BLUE/BLUE	1	4	1
BLUE	BROWN/BROWN	1	3	1
	BROWN/GREEN	5	13	5
	BROWN/BLUE	17	46	17
	GREEN/GREEN	0	0	0
	BLUE/GREEN	3	8	3
	BLUE/BLUE	11	30	11
HETEROCHROMIA	BLUE/BLUE	3	100	3

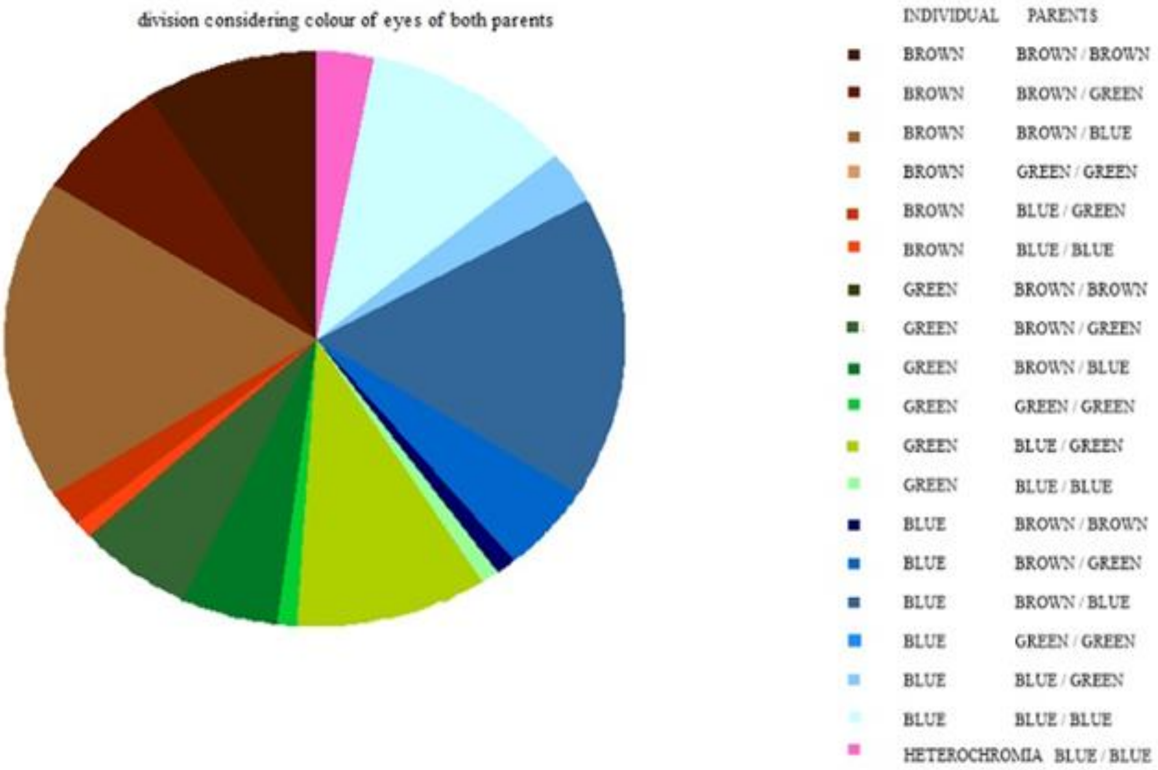
Table 5: Number and percentage of children with certain colour of eyes of parents having particular colours of iris

Colour of eyes of parents	Total number of individuals, whose parents have particular colours of eyes	Number and percentage of children with colour of eyes:							
		BROWN		GREEN		BLUE		HETEROCHROMIA	
		Number	Percentage [%]	Number	Percentage [%]	Number	Percentage [%]	Number	Percentage [%]
BROWN/BROWN	10	9	90	0	0	1	10	0	0
BROWN/GREEN	18	7	39	6	33	5	28	0	0
BROWN/BLUE	40	18	45	5	12.5	17	42.5	0	0
GREEN/GREEN	1	0	0	1	100	0	0	0	0
BLUE/GREEN	15	2	13	10	67	3	20	0	0
BLUE/BLUE	16	1	6	1	6	11	69	3	19

Graph 5: Percentages of children with particular colour of iris of couples with concrete colours of eyes



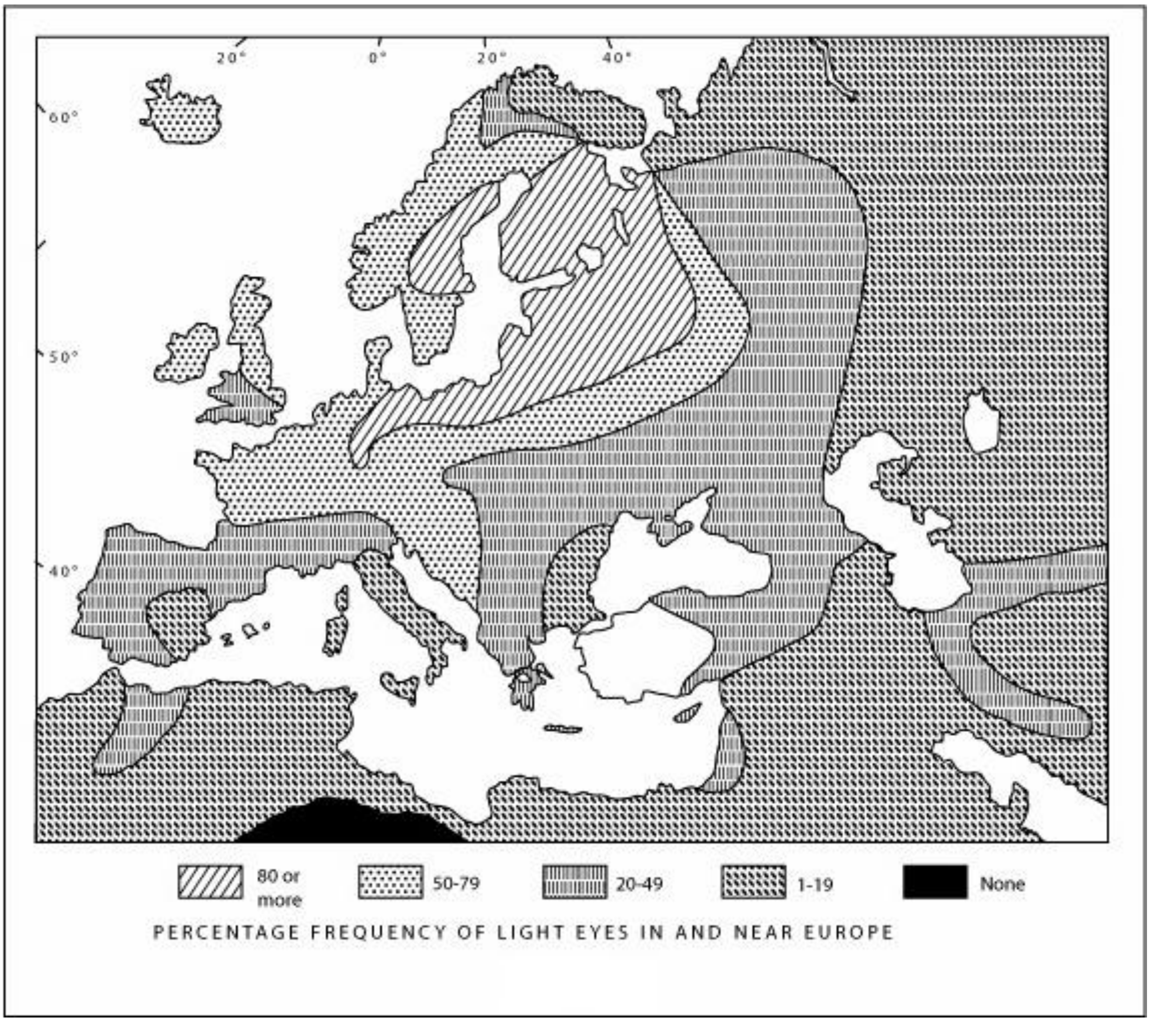
Graph 6: Percentage of all individuals (with brown, green, blue eyes and heterochromia



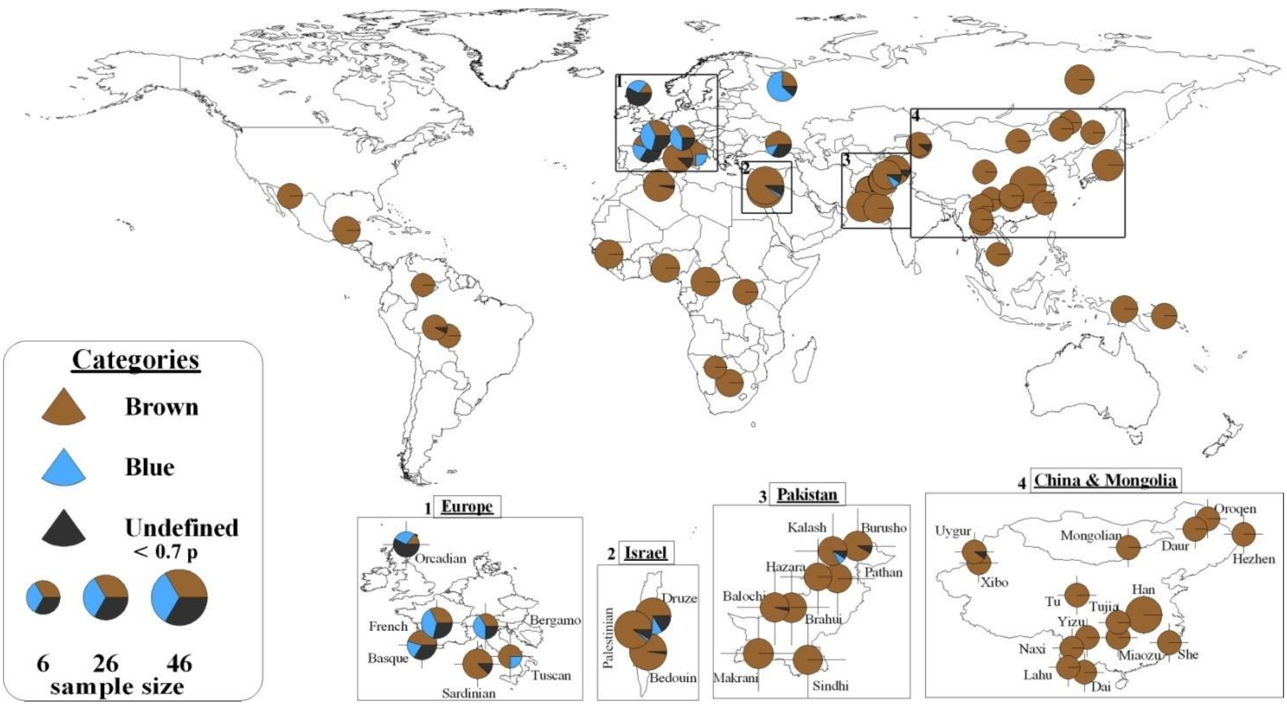
7. Conclusion

According to both table 1. and graph 1. which shows number of individuals having particular colour of iris, it is clearly visible that the number of people with brown and blue eyes is the same, each corresponds to 37 % of the investigated population (table 1.), which shows the inconsistency with stated earlier hypothesis. Number of individuals, whose iris has green colour is significantly smaller, represented by 23% of the investigated population (table 1.), which can be supported by the value of the percentage difference, which amounts to 47% (table 3.). Among investigated population there was also small percentage equal to 3% of whole population (table 4.) of individuals with *heterochromia iridum*. As far as inheritance of the investigated characteristic is concerned, according to both table 5. and graph 5., the greatest variation in colours of eyes of children can be observed in case of couples with brown and green eyes, namely, 39% of brown-eyed children, 33% of green-eyed ones, 28% of blue-eyed ones. Little smaller, but still clearly visible variation within gathered data is noticed in case of couples with brown and blue eyes (table 5. and graph 5.), namely, 45% - brown-eyed children, 12.5% of green-eyed ones, 42.5% of blue-eyed ones. These data confirm the existence of more than one gene responsible for inheritance of this feature – the cross of individuals having 2 different colours of eyes, for instance brown and green, can result in a child with another colour of iris, for instance blue. Another anomaly with respect to hypothesis can be visibly noticed as far as both parents with blue colour of iris have children with different than blue eyes (two cases: blue and green - table 4.). This fact suggests that there have to be more than three so far known genes coding for eye colour.

“Most humans have only one hair colour and one eye colour. Europeans are a big exception.(...) This diversity reaches a maximum in an area centered on the East Baltic and covering northern and eastern Europe.” (Frost, 2006) – it is the explanation of the results of distribution of the colour of the eyes in the given population – Poland, which was the place of the investigation, lies in eastern Europe, thus it is the exception in the global scale when it comes to the existance of greater variety and thereby greater amount of different than brown colours of people's irises. In other parts of the Earth, number of people with different than brown pigmentation of iris is very rare.



Picture 4: The map showing diversity of colour of eyes in and near Europe (Peter Frost, 2006 via Beals & Hoijer, 1965)



Picture 5: The world map of predicted eye colour based on genetic variants, from IrisPlex: A sensitive DNA tool for accurate prediction of blue and brown eye colour in the absence of ancestry information (2011)

According to picture 4., percentage frequency of light eyes in the area, where the data were collected (latitude and longitude coordinates of Kielce: 20°37'E; 50°53'N), is within the range 80-100 (the greatest).

Interestingly, all people with heterochromia from the investigated population have a connection of blue and brown colour of iris, where the blue one predominates (picture 1.) and all of them have both parents with blue eyes. The fact that two of them are related as well as the information that the grandmother of the third individual also had heterochromia (one eye blue, the second one blue with a brown sector) suggest that this feature is genetically determined. According to Amy Johnson (2012) the most probable reason of inheritance of heterochromia is Waardenburg syndrome. “The pigmentary defect of the iris which accompanies the syndrome has several noteworthy features. In the majority of the cases showing heterochromia iridum the lighter of the two irides was of a striking whitish-blue color of a form rarely encountered. (…)There were a few cases in which the aspect of pigmentation did not differ greatly between the two eyes and in which the lesser pigmented iris was not blue. Usually the cases of partial heterochromia showed blue sectors, sometimes in both irides at corresponding regions, sometimes in different regions on the only cases showing a small dark sector in a blue eye. The latter anomaly is also known to occur as an inherited trait. " (Waardenburg 1951).

Taking into account all of the information presented above, I am able to answer the research question, namely, the inheritance of the colour of human eyes is very complicated as my investigation clearly showed that there have to exist more than so far discovered genes, gey located on chromosome 19 and bey 1 and bey 2 both located on chromosome 15, which determine and influence the inheritance of this characteristic. What is more, carried out investigation showed the great variation in the colour of eyes in the given population, which lives in Poland, thus eastern Europe. This great variation can be supported by numbers, namely, 37% of the given population have brown eyes, the same percentage, 37% is equal to the number of individuals having blue eyes, and green-eyed people represent 23% of investigated population. Additionally, among the population there were also individuals with clearly visible *heterochromia iridum*, whose number was equal to 3%.

8. Evaluation

The greatest inconsistency with stated hypothesis is the fact, that the percentage of people with assumed as dominant colour of eyes – brown equals to the percentage of individuals with assumed as recessive colour of iris – blue. This is the result of not taking into account anthropological point of view. The fact that in Europe there is the greatest concentration of people with non-brown eyes significantly influenced the outcome. “Some believe it to be a side effect of natural selection for fairer skin to ensure enough vitamin D at northern latitudes.(...) Others put the cause down to intermixture with Neanderthals.(...) For others still, this colour diversity arose through random factors: genetic drift, founder effects, relaxation of natural selection, etc.” (Frost 2006). However, according to Frost (2006) the most probable reason of this phenomenon is “some kind of non-random process seems to have targeted hair and eye colour *per se*, that is, as visible characteristics. But how? And why? For some, including the geneticist Luigi L. Cavalli-Sforza, the answer is sexual selection (…) which was much stronger among ancestral Europeans than in other human populations. ”.

The greatest limitation of my investigation was the fact that the only possible and allowed to collect data, which would help to elaborate the topic, was the information of colour of the iris. The same visible feature could be the result of completely different combinations of genes, which was impossible to know during my investigation. Consequently, the methods of data processing were limited.

The fact that the issue of heritance of colour of eyes, among both humans and animals, is not completely understood yet, as far as the examinations of human genome conducted in order to find other genes influencing this feature still last. There are proves that there must be other genes responsible for eye colour determination, like for instance the exceptions of my investigation, which do not coincide with the hypothesis, namely, the children of both blue-eyed parents could have different that blue colour of iris. This theoretical anomaly leads to the following consideration: provided that the blue colour was the recessive feature on all three known so far genes responsible for this inheritance, the existence of completely different that blue colours of iris, assuming that shades of blue are considered as the result of mutation, would be impossible.

Another important issue, which could have an impact on the results, but was not taken into account, is the fact that the colour of eyes is linked to colour of hair and skin. In all three cases there is an influence of different versions of pigment melanin. What is more, skin and hair have much greater surface area influenced by pigment than in case of irises. Taking it into consideration, we can assume that if colours of skin and hair were examined, in cases of anomalies with respect to hypothesis such as blue-eyed parents with different-eyed children, the theoretical distribution of melanin receptors based on hair and skin could be observed and linked with the picture of eyes. It could also suggest whether the mutation is the reason of unexpected results or not

Inheritance of colour of eyes, not only in human, but also among all species of mammals, seems to be very complicated. The fact that brilliant scientists with access to high technology of examinations of the genome have not discovered so far the way of inheritance of this characteristic and all responsible for it genes, is the best evidence of complexity of this characteristic, seemingly so simple because of commonness in our everyday life. What is more, my investigation showed me how many factors affects the occurrence of one characteristic.

9. Cited references

1. [Anonymous]. Eye Color Guide - The Most Common Eye Colors. 2014. AC Lens.
   Available from: http://www.aclens.com/Most-Common-Eye-Color-c323.html
   Accessed 2014 November 25

2. [Anonymous]. Heterochromia iridis . 2011. Genetic and Rare Diseases Information Center (GARD).
   Available from:
   http://rarediseases.info.nih.gov/gard/8590/heterochromia-iridis/resources/1
   Accessed 2014 November 25

3. [Anonymous]. Oculocutaneous albinism. 2007. The U.S. National Library of Medicine.
   Available from: http://ghr.nlm.nih.gov/condition/oculocutaneous-albinism
   Accessed 2014 November 25

4. [Anonymous]. What is albinism? 2002. The National Organisation for Albinism and Hypopigmentation.
   Available from: http://www.albinism.org/publications/what_is_albinism.html
   Accesed 2014 November 25

5. Damon A, McGonegal R, Tosto P, Ward W. 2007. Biology. Edinburgh: Pearson Baccalaureate.

6. Editors of the American Heritage Dictionaries. 2002. The American Heritage Stedman's Medical Dictionary. Albino. Boston: Houghton Mifflin Company. Available from: http://dictionary.reference.com/browse/albino.
   Accessed 2014 November 25.

7. Editors of the American Heritage Dictionaries. 2002. The American Heritage Stedman's Medical Dictionary. Heterochromia. Boston: Houghton Mifflin Company. Available from: http://dictionary.reference.com/browse/heterochromia. Accessed 2014 October 6.

8. Editors of the American Heritage Dictionaries. 2002. The American Heritage Stedman's Medical Dictionary. Melanin. Boston: Houghton Mifflin Company. Available from: http://dictionary.reference.com/browse/melanin Accessed 2014 October 6.

9. Frost P. 2006. Why Do Europeans Have So Many Hair and Eye Colors? Université Laval and St. Andrews University [online]. Available from: http://cogweb.ucla.edu/ep/Frost_06.html. Accessed 2014 October 6.

10. Frudakis T, Thomas M, Gaskin Z, Venkateswarlu K, Chandra K S, Ginjupalli S, Gunturi S, Natrajan S, Ponnuswamy V K, Ponnuswamy K N.Sequences associated with human iris pigmentation. Genetics Society of America [online]. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1462887/pdf/14704187.pdf Accessed 2014 October 5.

11. Johnson A. 2012. Eye Color. Stanford at The Tech Museum of Innovation [online]. Available from: http://genetics.thetech.org/ask-a-geneticist/inheritance-heterochromia Accessed 2014 October 13

12. Malinowski E. 1974. Genetyka. Warszawa: Państwowe Wydawnictwo Naukowe

13. Montgomery T. 1998. Anatomy, physiology and pathology of the human eye. The iris.
Available from: http://www.tedmontgomery.com/the_eye/iris.html.
Accessed 2014 October 6

14. Muron A, Pospisil J. 2000.The human iris structure and its usages. Department of Experimental Physics, Natural Science Faculty of Palacký University [online]. Available from:
http://publib.upol.cz/~obd/fulltext/Physica%2039/Physica%2039_07.pdf
Accessed 2014 October 5.

15. Seddon J M, Sahagian C R, Glynn R J, Sperduto R D, Gragoudas E . 1990. Evaluation of an Iris Color Classification System. Boston: Massachusetts Eye and Ear Infirmary, Epidemiology Unit.
Available from: http://www.iovs.org/content/31/8/1592.full.pdf+html.
Accessed 2014 November 25

16. Waardenburg P J. 1951. A new syndrome combining developmental anomalies of the eyelids, eyebrows and noseroot with pigmentary anomalies of the iris and head hair and with congenital deafness; Dystopia canthi medialis et punctorum lacrimalium lateroversa, hyperplasia supercilii medialis et radicis nasi, heterochromia iridum totaliis sive partialis, albinismus circumscriptus (leucismus, polioss) et surditas congenita (surdimutitas). American Journal of Human Genetics.
Available from:
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1716407/?page=1.
Accessed 2014 November 25

10. Appendix

- A few examples of simple Punett Squares, which consideres 2 genes (bey 2; gey) as the only ones responsible for inheritance of the eye colour

1)

Parent 1: BEY 2: brown-brown GEY: blue-blue

Parent 2: BEY 2: brown-brown GEY: blue-blue

	brown blue	brown blue	brown blue	brown blue
Brown Blue	brown-brown blue-blue	brown-brown blue-blue	brown-brown blue-blue	brown-brown blue-blue
Brown Blue	brown-brown blue-blue	brown-brown blue-blue	brown-brown blue-blue	brown-brown blue-blue
Brown Blue	brown-brown blue-blue	brown-brown blue-blue	brown-brown blue-blue	brown-brown blue-blue
Brown Blue	brown-brown blue-blue	brown-brown blue-blue	brown-brown blue-blue	brown-brown blue-blue

2)

Parent 1: BEY 2: brown-brown GEY: blue-blue

Parent 2: BEY 2: blue-blue GEY: blue-blue

	brown blue	brown blue	brown blue	brown blue
Blue Blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue
blue blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue
blue blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue
blue blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue

3)

Parent 1: BEY 2: brown-brown GEY: green-green

Parent 2: BEY 2: brown-brown GEY: blue-blue

	brown green	brown green	brown green	brown green
brown blue	brown-brown green-blue	brown-brown green-blue	brown-brown green-blue	brown-brown green-blue
brown blue	brown-brown green-blue	brown-brown green-blue	brown-brown green-blue	brown-brown green-blue
brown blue	brown-brown green-blue	brown-brown green-blue	brown-brown green-blue	brown-brown green-blue
brown blue	brown-brown green-blue	brown-brown green-blue	brown-brown green-blue	brown-brown green-blue

4)

Parent 1: BEY 2: brown-blue GEY: blue-blue

Parent 2: BEY 2: brown-blue GEY: blue-blue

	brown blue	brown blue	blue blue	blue blue
brown blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue
brown blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue	brown-blue blue-blue
blue blue	brown-blue blue-blue	brown-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue
blue blue	brown-blue blue-blue	brown-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue

5)

Parent 1: BEY 2: brown-blue GEY: blue-blue

Parent 2: BEY 2: blue-blue GEY: blue-blue

	brown	brown	blue	blue
	blue	blue	blue	blue
blue blue	brown-blue blue-blue	brown-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue
blue blue	brown-blue blue-blue	brown-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue
blue blue	brown-blue blue-blue	brown-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue
blue blue	brown-blue blue-blue	brown-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue

6)

Parent 1: BEY 2: blue-blue GEY: blue-blue

Parent 2: BEY 2: blue-blue GEY: blue-blue

	blue	blue	blue	blue
	blue	blue	blue	blue
blue blue	blue-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue
blue blue	blue-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue
blue blue	blue-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue
blue blue	blue-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue	blue-blue blue-blue

Table 6: Raw data including colour of eyes of investigated individual and their's closest family divided into three groups depending on the colour of eyes of investigated individual

	Colour of eyes	Colour of mother's eyes	Colour of father's eyes	Colour of siblings' eyes		
1	Brown	Brown	Brown	Brown	Brown	
2	Brown	Brown	Blue	Brown		
3	Brown	Blue	Brown	Brown	Brown	Brown
4	Brown	Brown	Brown	Green		
5	Brown	Brown	Blue	Blue		
6	Brown	Brown	Blue	Brown	Brown	
7	Brown	Brown	Brown	Brown		
8	Brown	Brown	Brown	Brown		
9	Brown	Brown	Blue			
10	Brown	Brown	Blue	Green		
11	Brown	Brown	Brown	Brown		
12	Brown	Blue	Brown			
13	Brown	Brown	Blue	Brown		
14	Brown	Blue	Brown	Brown		
15	Brown	Blue	Brown	Brown	Brown	
16	Brown	Green	Brown	Blue		
17	Brown	Blue	Brown			
18	Brown	Blue	Brown	Brown		
19	Brown	Green	Blue	Green		
20	Brown	Brown	Blue	Brown	Brown	Green
21	Brown	Green	Brown			

22	Brown	Brown	Blue			
23	Brown	Green	Brown	Brown		
24	Brown	Brown	Blue	Brown		
25	Brown	Brown	Blue	Brown		
26	Brown	Blue	Green	Brown		
27	Brown	Brown	Green	Brown		
28	Brown	Brown	Brown			
29	Brown	Brown	Brown	Brown		
30	Brown	Brown	Blue			
31	Brown	Brown	Blue	Brown	Brown	Blue
32	Brown	Blue	Brown	Brown		
33	Brown	Blue	Brown			
34	Brown	Green	Brown	Brown		
35	Brown	Brown	Brown			
36	Brown	Green	Brown			
37	Brown	Brown	Green	Brown	Brown	
38	Green	Green	Green	Green		
39	Green	Green	Blue	Green	Green	
40	Green	Blue	Brown	Brown		
41	Green	Blue	Green			
42	Green	Brown	Blue	Brown	Brown	
43	Green	Green	Brown			
44	Green	Green	Brown	Blue		
45	Green	Green	Blue	Blue		
46	Green	Green	Blue	Green		

47	Green	Green	Blue	Blue		
48	Green	Green	Blue	Blue		
49	Green	Brown	Green	Brown		
50	Green	Green	Blue	Blue		
51	Green	Blue	Brown			
52	Green	Green	Brown	Brown		
53	Green	Brown	Blue	Green		
54	Green	Blue	Brown	Brown		
55	Green	Brown	Green	Brown		
56	Green	Green	Brown	Green	Brown	
57	Green	Blue	Green	Blue		
58	Green	Green	Blue	Blue		
59	Green	Blue	Green	Brown	Green	
	Green	Green	Blue	Blue		
60						
61	Blue	Blue	Brown	Brown	Brown	
62	Blue	Blue	Brown	Blue		
63	Blue	Brown	Blue	Blue		
64	Blue	Brown	Blue	Brown		
65	Blue	Blue	Brown	Brown	Blue	
66	Blue	Blue	Blue	Blue	Blue	
67	Blue	Brown	Green	Green		
68	Blue	Brown	Blue	Brown	Brown	
69	Blue	Blue	Blue	Blue		
70	Blue	Blue	Blue			
71	Blue	Blue	Blue	Blue		

72	Blue	Green	Blue	Green		
73	Blue	Blue	Blue	Blue	Green	Green
74	Blue	Blue	Brown	Blue		
75	Blue	Blue	Blue			
76	Blue	Brown	Blue	Brown	Brown	
77	Blue	Blue	Brown	Brown		
78	Blue	Blue	Blue	Blue	Blue	
79	Blue	Brown	Brown			
80	Blue	Brown	Blue	Brown		
81	Blue	Blue	Brown	Blue	Brown	
82	Blue	Blue	Blue	Blue		
83	Blue	Blue	Blue	Blue		
84	Blue	Blue	Brown	Blue		
85	Blue	Blue	Blue	Blue		
86	Blue	Blue	Blue	Blue		
87	Blue	Brown	Green	Brown		
88	Blue	Blue	Blue	Blue		
89	Blue	Green	Blue	Blue	Green	
90	Blue	Green	Brown	Brown		
91	Blue	Blue	Brown	Brown		
92	Blue	Blue	Green	Blue		
93	Blue	Blue	Brown	Brown		
94	Blue	Brown	Blue	Blue		
95	Blue	Blue	Brown	Brown		
96	Blue	Blue	Brown			
97	Blue	Green	Brown			

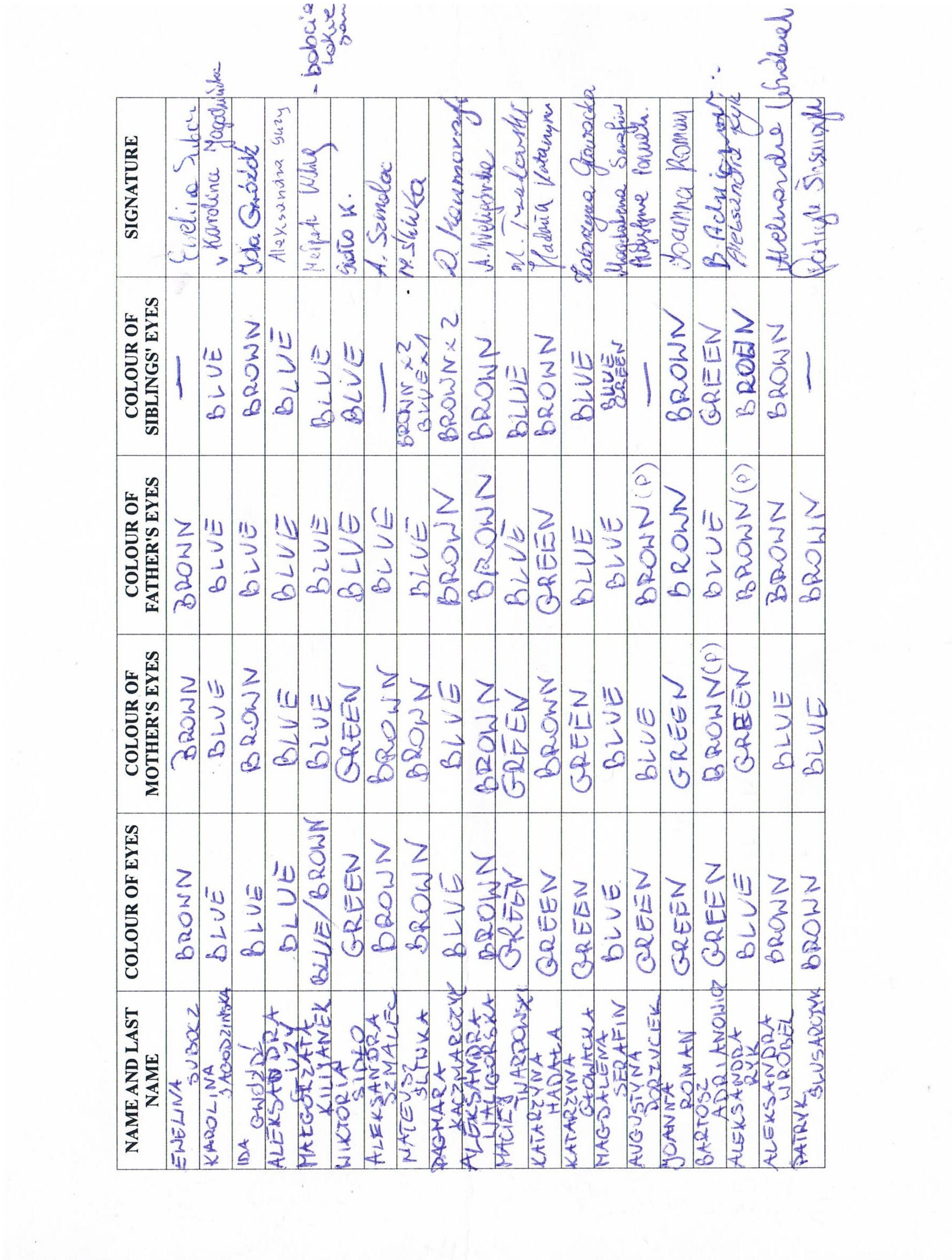
98	Blue	Green	Brown	Brown	Brown	Brown
99	Blue|Blue/Brown	Blue	Blue	Blue		
100	Blue|Blue/Brown	Blue	Blue	Blue		

Picture 6: Another example of individual, which was classified as a person with heterochromia

Picture 7: An example of individual, which was classified as a person with blue colour of eyes

Picture 8: An example of individual, which was classified as a person with green colour of eyes

Picture 9: An example of individual, which was classified as a person with brown colour of eyes



NAME AND LAST NAME	COLOUR OF EYES	COLOUR OF MOTHER'S EYES	COLOUR OF FATHER'S EYES	COLOUR OF SIBLINGS' EYES	SIGNATURE
EWELINA SUBOCZ	BROWN	BROWN	BROWN	—	Ewelina Subocz
KAROLINA JAGODZIŃSKA	BLUE	BLUE	BLUE	BLUE	Karolina Jagodzińska
IDA GWÓŹDŹ	BLUE	BROWN	BLUE	BROWN	Ida Gwóźdź
ALEKSANDRA GUZY	BLUE	BLUE	BLUE	BLUE	Aleksandra Guzy
MAŁGORZATA KILIJANEK	BLUE/BROWN	BLUE	BLUE	BLUE	Małgorzata Kilijanek - bobcia Lokwe gam
WIKTORIA SIDŁO	GREEN	GREEN	BLUE	BLUE	Sidło K.
ALEKSANDRA SZMALEC	BROWN	BROWN	BLUE	—	A. Szmalec
MATEUSZ SLIWKA	BROWN	BROWN	BLUE	BROWN x2 BLUE x1	M. Śliwka
DAGMARA KACZMARCZYK	BLUE	BLUE	BROWN	BROWN x 2	D. Kaczmarczyk
ALEKSANDRA WALIGÓRSKA	BROWN	BROWN	BROWN	BROWN	A. Waligórska
MACIEJ TWARDOWSKI	GREEN	GREEN	BLUE	BLUE	M. Twardowski
KATARZYNA HADAŁA	GREEN	BROWN	GREEN	BROWN	Hadała Katarzyna
KATARZYNA GŁOWACKA	GREEN	GREEN	BLUE	BLUE	Katarzyna Głowacka
MAGDALENA SERAFIN	BLUE	BLUE	BLUE	BLUE GREEN	Magdalena Serafin
AUGUSTYNA DORZYCEK	GREEN	BLUE	BROWN (P)	—	Augustyna Porwoła [illegible]
JOANNA ROMAN	GREEN	GREEN	BROWN	BROWN	Joanna Roman
BARTOSZ ADRIANOWICZ	GREEN	BROWN(P)	BLUE	GREEN	B. Adrianowicz
ALEKSANDRA RYK	BLUE	GREEN	BROWN (P)	BROWN	Aleksandra Ryk
ALEKSANDRA WRÓBEL	BROWN	BLUE	BROWN	BROWN	Aleksandra Wróbel
PATRYK ŚLUSARCZYK	BROWN	BLUE	BROWN	—	Patryk Ślusarczyk

Picture 10: An example of a filled worksheet