Research Article

A Cross-National Study of Students' Understanding of Genetics Concepts: Implications from Similarities and Differences in England and Turkey

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This research is aimed at exploring 16- to 19-year-old students' understanding of fundamental genetics concepts, which has considerable importance for developing conceptual understanding of genetics related phenomena. A cross-national descriptive research method was used to explore English and Turkish students' understandings of genetics concepts. Data were collected by a two-tier multiple choice diagnostic instrument, The Two-Tier Genetics Concept Test, which required students to justify their choice of option by giving a reason. The results indicate that there are some differences between the English students' and Turkish students' understanding of fundamental concepts of genetics; however, there are some notable similarities between the alternative conceptions held by students in the two samples. The common alternative conceptions seen in both of the groups indicate that understanding the concepts occurred regardless of contextual factors. Nevertheless different proportions of the common alternative conceptions and different levels of understanding suggest that conceptualisations develop under the influence of different educational contexts.

1. Introduction

Expectations and uncertainties created by the advancements in the field of genetics both excite and concern people. This is partially because genetics research proceeds rapidly, genetics phenomena are complex, and the amount of information related to advances in genetics is continuously increasing. In recent decades there have been a wide range of scientific and technological advances in this field such as the human genome project, cloning, genetically modified foods, gene therapy, and treatment of diseases including a wide variety of cancers, heart disease, and diabetes. News about research and development in the field of genetics is difficult for people to understand. An increasing number of articles in newspapers, journals, and books indicate that there is a growing consensus among science educators that students need a better understanding of basic genetics concepts [1]. With the increasing importance of genetics in daily life, there is a need to pay greater attention to the subject of genetics

in the school science curriculum [2]. Genetics instruction at secondary school also provides a considerable opportunity to discuss current ethical and social issues [3]. According to Lewis et al. [4–6] individuals in secondary level schooling should be able to understand what they hear and read about genetics and they should be able to give an informed response to personal or social issues with a science content.

More than 30 years ago, Johnstone and Mahmoud [7] examined the topics of high perceived difficulty in school biology syllabus and they revealed that the topics found to be difficult by students are related to genetics (e.g., DNA and RNA, gametes, and genes). Research carried out in the following years has consistently confirmed that genetics was among the subjects regarded to be difficult to understand by students [8–14]. Knippels et al. [15] reviewing studies in the field of genetics education revealed some major difficulties experienced by students which are (a) the domain-specific vocabulary and terminology, (b) the mathematical content of Mendelian genetics tasks, (c) the cytological processes, and

(d) the abstract and complex nature of genetics. According to Duncan and Reiser [10], genetics is difficult for students to learn because of the invisibility and inaccessibility of genetic phenomena. Moreover, genetics requires a certain level of abstract thought and this is one of the reasons accounting for the difficulty of understanding genetics [9]. Formal operational thinking is needed to think of reality in a multivariate way, so as to make a general or abstract formulation of a relationship [16]. Another reason behind the difficulty of learning and teaching genetics subjects is that these subjects include concepts (genes, proteins, cells, tissues, organs, etc.) belonging to different levels of a biological organism (macro, micro, and molecular levels). In order to understand the underlying processes of genetic phenomena, there is a need for students to be informed about different levels in an integrated manner, as in this way students can grasp genetics as a whole [8, 10, 12]. In addition, there are many terms which are look-alike and sound-alike in genetics [8] and there are many synonymous words involved in genetic terms [17], and this leads to students' confusing these terms and having difficulties in understanding genetics.

1.1. Research Rationale. Taber [18] emphasized that "understanding of a topic at a more advanced level usually presumes an understanding of more fundamental ideas that may have been met earlier during less advanced levels" (p. 150). As a lack of scientifically sound understanding limits further learning [19], a prerequisite for students to learn genetics subjects meaningfully is to understand fundamental genetics concepts accurately. Attaining a meaningful understanding of genetics requires relevant and coherent conceptual structure built up through iterative processes. The constructivist perspective suggests that learning always builds upon and interacts with the cognitive and conceptual resources already available [20]. One of the main factors determining whether learning material is potentially meaningful depends on the availability of the relevant content in the cognitive structure of the particular learner [21]. It has been suggested that it is important to consider a learner's current state of knowledge and understanding in teaching; otherwise misinterpretations, failures to make expected links, and making inappropriate links can take place [22]. Inadequacy in understanding fundamental concepts and also in relating new learning material with the existing conceptual framework in canonical ways constitutes impediments for further meaningful learning. Therefore, one of the foci of this research is to examine students' understanding of fundamental genetics concepts such as gene, DNA, chromosome, and inheritance, which have considerable importance for developing conceptual understanding of genetics related phenomena.

From an international perspective of science education, it is important to reveal how universal students' conceptions are [23] and how contextual factors can affect students' conceptions. Taber [24] argued that the research to compare learners' ideas from diverse educational contexts can be helpful to identify which classes of influences are significant in the formation of understanding. There is a body of research that investigated students' understanding of genetics from different aspects in various countries: however there is

a considerable lack of cross-national studies focusing on the generality and diversity of students' conceptual understanding of genetics. With this study, it is expected to contribute to a better understanding on how the similarities and differences between English and Turkish students' understanding of genetics have been influenced by national educational contexts.

1.2. Genetics Education in the English and Turkey School Curricula. Genetics related subjects in the English National Curriculum programmes of study for science at Key Stage 3 and Key Stage 4 (Years 7–9 and Years 10-11) are variation, classification, inheritance, and evolution. At further education (Year 12 and Year 13) that occurs following compulsory secondary education, genetics topics include the units of Genes and Health, Cellular Control, Genomes, Biotechnology, and Gene Technologies. These units include the topics of DNA and RNA; cellular control; replication; protein synthesis; meiosis and mitosis; inheritance; genomes; and gene technologies. In Turkey students at secondary school level start learning genetics related subjects at 9th grade within the context of biology courses under the unit of "Life Science Biology." This unit includes the topics of structure and functions of DNA and RNA. At 10th grade the units of "Reproduction" and "General Principles of Inheritance" cover the topics of mitosis and meiosis; inheritance; principles of Mendelian inheritance; modern genetics; biotechnology; and genetic engineering. At 12th grade, students learn about the discovery and importance of nucleic acids; the genetic code; and protein synthesis under the unit of "From Gene to Protein."

1.3. Purpose and Research Questions. Taber [24] emphasized that studies from different contexts have potential to make a significant contribution to the field, considering how the different contexts might have influenced the similarities and differences between the aspects of students' thinking. Accordingly, the purpose of the study presented in this paper was to investigate similarities and differences in understanding of genetics concepts between students from two different educational systems, England and Turkey. It was also aimed at exploring the levels of support for alternative conceptions that are common and different among English and Turkish students.

More specifically, the research questions were as follows:

(1) How well do English and Turkish students understand key concepts and relationships commonly taught in high school genetics?

(2) To what extent do English and Turkish students demonstrate evidence of sharing common alternative conceptions about genetic concepts?

(3) Can any differences found between the English and Turkish samples be related to the nature of the curricula?

2. Methodology

Consistent with the purpose of the study and research questions, a cross-national design was conducted to explore

English and Turkish students' understanding of genetics concepts. With the aim of gaining insight into students' understanding of genetics, a quantitative survey approach was followed in which the participants were required to complete a paper and pencil instrument.

2.1. Participants. Students in the age range 16–19 were selected as the participants of this study because students between these ages in both England and Turkey had already experienced teaching on the entire content of the genetics related subjects in accordance with their own biology curriculum. Concerning the differences between education systems in both countries, participants of the research were nominally studying at different educational levels; English students were in Year 12 or Year 13 in further education while Turkish students were in the 12th grade of secondary education. In total, 779 students participated in the study. 586 students (269 girls, 317 boys) from Turkey were selected through stratified random sampling. These students attended three different types of secondary schools and followed the same biology curriculum in Turkey. A total of 193 English students (104 girls, 83 boys, and 6 unknown) from three different sixth-form colleges participated in the study. One limitation of the study results from the difficulties of conducting research in various schools in England; this led to the selection of English students through convenience sampling. In particular, all of the English students had voluntarily entered an "academic stream" at age 16 and to some extent had been selected as admission to the courses is not automatic.

2.2. Data Collection. In the present study, a two-tier multiple choice diagnostic instrument, The Two-Tier Genetics Concept Test (TGCT), which required students to justify their choice of option by giving a reason, was used to identify students' understanding of genetics concepts. The items in two-tier multiple choice diagnostic instruments are specifically designed to identify alternative conceptions and misunderstandings in a limited and clearly defined content area [25]. TGCT was developed in a previous study [26] to elicit data about students' understanding of fundamental concepts of genetics such as DNA, gene, chromosome, and relationships among these concepts and the relationships between cell divisions and inheritance. Each item on the test was made up of two questions, where the first objective type question was designed to test students' knowledge on genetics concepts; and the second question elicited the reason for the response given by students for the first question. The first tier of each item on the test contained a three-option content question, whereas the second tier contained a set of five possible reasons for the option chosen in the first tier question.

2.2.1. Development of the Turkish Version of the TGCT. While developing TGCT, a ten-step method involving three main phases, as proposed by [25], was followed. In the first phase, the content of the topic was determined. For this purpose, biology curriculum, textbooks, and supplementary books were examined and 25 propositional knowledge statements, containing all aspects of relevant topics and concepts, were identified. Also a concept map that accommodates the propositional statements was constructed. In the second phase for obtaining information about students' conceptions, relevant literature was reviewed, semistructured interviews were conducted with 21 students, and a multiple choice test with free response answers was administered to 120 students. Thus, data about students' misunderstandings concerning the fundamental concepts of genetics were obtained. In the third phase, multiple choice two-tier test items directed to determining students' understanding of genetics concepts were developed through item analysis and evaluation of student responses. Consequently, the TGCT consisting of 14 items was constructed and administered to 231 secondary school students to conduct test reliability and item analyses. The psychometric characteristics of the test (discrimination indices, difficulty indices, and the functionality of the distracters) were examined by item analyses and the findings demonstrated that the items functioned in a satisfactory way. Cronbach's alpha reliability coefficient of the Turkish version of the TGCT was found to be 0.82 [26].

2.2.2. Development of the English Version of the TGCT. For the present study, the Turkish version of the TGCT was translated into English by two university lecturers in Turkey. One of the lecturers is a specialist on genetics and the other one is a university reader in English language teaching. These two translated versions were examined and incorporated by a native English university lecturer, a specialist in biology education. Some revisions were made on items to make them clearer and understandable to English students. Also one item was removed from the test as a consequence of the expert opinions. That item was about the relation between gene and DNA, which can be explained from different perspectives. In English biology curriculum it is highlighted that "gene is made up of DNA," while in Turkish curriculum it is emphasized that "gene is a certain length of DNA." The difference of wording would require a change in not only the question but also the distractors. So it was decided to remove that item from the test, as this reduction would not cause a significant difference for the content of the test since there were two other items in the TGCT that addressed the relations between gene and DNA. Consequently, the English version of the TGCT comprised 13 items (cf. 14 items on the Turkish version) but however involved the same target concepts and phenomena as the Turkish version. The final form of the English version of the test (see the Appendix) was found to be appropriate for use in terms of its readability and wording after examining by a native English biology teacher.

In order to examine the psychometric characteristics of the English version of the TGCT the data obtained from the administrations were analysed. Item discrimination indices were found to be between 0.31 and 0.67. Item difficulty indices showed a wide distribution between 0.11 and 0.74, which contribute to measuring differences. The average of item difficulty values was found to be around 0.50. Cronbach's alpha reliability coefficient of the English version of the TGCT was found to be 0.82. Consequently, the results of item and test analyses showed that items functioned well and that there was no need for modifications.

TABLE 1: The percentage of students' correct answers to the first tier and to both tiers of items in TGCT relating to the conceptual categories.

Conceptual categories	Item number	English students		Turkish students	
		First tier	Both tiers	First tier	Both tiers
		%	%	%	%
Gene concept	(2)	62.2	48.2	38.6	23.4
	(5)	75.6	73.6	43.0	37.0
	(7)	75.1	43.0	42.7	31.1
	Mean	70.97	54.93	41.43	30.50
Chromosome concept	(3)	28.5	11.4	70.5	32.4
	(8)	53.4	50.3	23.5	20.5
	(13)	36.3	27.5	32.1	20.0
	Mean	39.40	29.73	42.03	24.30
Relationships among gene, chromosome, and DNA	(1)	80.8	72.0	42.3	36.9
	(4)	58.5	56.5	39.6	31.4
	(10)	57.0	42.0	53.8	27.3
	Mean	65.43	56.83	45.23	31.86
Relationships between cell divisions and inheritance	(6)	86.0	74.1	63.5	56.5
	(9)	48.7	39.9	56.3	49.5
	(11)	85.5	70.5	68.8	55.5
	(12)	73.1	61.7	68.9	45.7
	Mean	73.33	61.55	64.38	51.80

2.3. Data Analysis. The data obtained from the administration of TGCT were analysed using the SPSS software programme for both correct and incorrect response combinations selected by students. An item was scored as correct when both of the tiers (content knowledge and reason) were answered correctly. The percentage of students' correct answers to first tiers and to both tiers of each item within related conceptual categories was tabulated and graphs were generated. A multivariate analysis of variance was performed to determine the significance of the differences between English and Turkish students in understanding genetics concepts within the conceptual categories.

Although there were only 13 items that students in both samples responded to, the use of a two-tier instrument gives the possibility of identifying the incidence of more than one alternative conception for each item (as distractors for each item were selected based on the comments made by students in the interviews during the development of the instrument). Analysis of incorrect response combinations provided data on students' alternative conceptions related to that specific item. Incorrect response combinations were considered as an alternative conception if they existed in at least 10% of the student samples [27]. Students' alternative conceptions were clustered into the categories related to the target concepts and phenomena. The similarities and differences between English and Turkish students' alternative conceptions were specified by examining the conceptual categories.

3. Results

The results are presented in three sections, each of which corresponds to the research questions of this study. At first, the results related with English and Turkish students'

understanding of the key concepts of genetics are presented. Secondly, the findings concerning which alternative conceptions were found to be common among the English and Turkish students are displayed. In the third section, the results regarding the differences between English and Turkish samples related to the nature of curricula are presented.

3.1. English and Turkish Students' Understanding of Fundamental Genetics Concepts. After the examination of English and Turkish students' responses to the test items, the percentage of the correct answers to the first tiers and to both tiers of items were determined. The results of the analyses of students' correct answers were summarized by conceptual categories in Table 1 for each of the samples.

A comparison of the percentage of students (both English and Turkish) who correctly answered the content part of the questions (first tiers) with that of those who correctly answered both parts of the questions suggested that many students have learned facts without an adequate understanding of the properties and concepts involved [28]. As can be seen in Table 1, the percentages of English students' responses considered as correct answers to both tiers of items within conceptual categories are higher than the percentage of Turkish students' responses considered as correct answers. The graph showing the percentage of English and Turkish students' answers coded as correct to both tiers of items for each conceptual category is presented in Figure 1.

When the percentage of students' responses to the items was evaluated according to the conceptual categories, it can be seen from the figure that the differences are in favor of English students for each of the conceptual categories. A multivariate analysis of variance was performed to determine the significance of the differences between English

TABLE 2: Follow-up univariate analyses.

Conceptual categories	df	F	p
Gene concept	1	71.061	0.000*
Chromosome concept	1	4.88	0.027
Relationships among gene, chromosome, and DNA	1	77.466	0.000*
Relationships between cell divisions and inheritance	1	12.110	0.001*

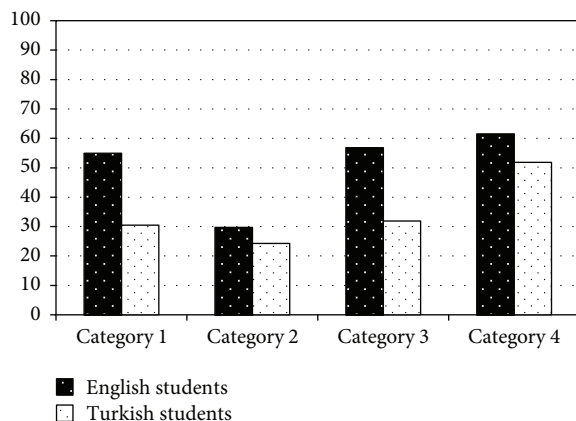*F values are significant at the 0.0125 significance level.

FIGURE 1: The percentages of English and Turkish students' who provided correct responses to both tiers of test items relating to the four conceptual categories.

and Turkish students in understanding the four conceptual categories. Before conducting the analysis, the assumptions of MANOVA were checked and findings indicated that the assumption of equality of the covariance matrices was met (Box's $M = 14.43$, $p > 0.05$). The results of MANOVA revealed that there was a significant main effect for sample, indicating an overall significant difference in understanding conceptual categories between the two separate samples (Wilks' $\lambda = 0.87$; $F(4, 774) = 28.47$; $p = 0.000$). Bonferroni adjustment was utilized to evaluate further univariate F statistics and assumed alpha level of 0.05 divided by the number of dependent variables (i.e., four). Therefore, obtained F statistics were evaluated at the alpha level of 0.0125. Table 2 displays the results of follow-up univariate analyses, which revealed that there were significant differences on dependent variables between English and Turkish students for all conceptual categories except the category of chromosome concept.

The univariate F tests showed that there were significant differences between English and Turkish students for understanding of gene concept ($F = 71.061$, $p < 0.0125$), for understanding of relationships among gene, chromosome, and DNA ($F = 77.466$, $p < 0.0125$), and for understanding of relationships between cell divisions and inheritance ($F = 12.110$, $p < 0.0125$). However, the F test for understanding of chromosome concept was not significant ($F = 4.88$, $p > 0.0125$), indicating that English and Turkish students were not significantly different in understanding the chromosome concept.

3.1.1. Students' Understanding of Gene Concept. As a response to item (2) "which cells of an individual contain the genes that determine his/her inherited characteristics?" 48% of the English students and 23% of the Turkish students stated that chromosomes containing the genes which determine the inherited characteristics are found in all cells. In response to item (5) "where is the gene for eye colour located?" 74% of the English students and 37% of the Turkish students stated that it is found in all cells. Another item in this category is item (7) and this item expects students to state that in all the somatic cells of an individual, there are the same genes; hence, eye and skin cells have the identical genetic information. 43% of the English students and 31% of the Turkish students responded to item (7) correctly. The proportion of the English students giving correct answers to all of the three questions in this category was 26% and that of the Turkish students was 11%.

3.1.2. Students' Understanding of Chromosome Concept. For item (3) asking number of chromosomes of an organism whose chromosome formula is given, 11% of the English students and 32% of the Turkish students stated that the number of chromosomes of an organism is equal to the number of sex chromosomes and somatic chromosomes added together. This is the item to which the English students gave the fewest correct answers. While the proportion of the English students stating that chromosomes which determine sex of an organism are located in all the cells was 50%, it was 21% for the Turkish students (item (8)). For item (13) asking how the genes of parents are transferred to the offspring, 28% of the English students and 20% of the Turkish students responded that sex cells carry both sex chromosomes and somatic chromosomes. In this category where correct response proportion for the items is the lowest for both English students and Turkish students, the proportion of the English students who responded to all the items correctly was 4% and that of the Turkish students was 6%.

3.1.3. Students' Understanding of Relationships among Gene, Chromosome, and DNA. Item (1) concerning the students' understanding of the location of gene, chromosome, and DNA was responded to correctly by 72% of the English students and 37% of the Turkish students. The proportion of the English students stating that there is DNA in the structure of chromosomes and that sex chromosomes are not only present in sex cells but also in all the cells was 57% and that of the Turkish students was 31% (item (4)). For another item related to relationships among gene, chromosome, and DNA (item (10)), 42% of the English students stated that

genes are located on chromosomes and they are made up of DNA and all somatic cells have the same genes. For the same item, 27% of the Turkish students stated that genes which are the segments of DNA are located on chromosomes and all somatic cells of an individual have the same genes. The proportion of the English students responding to all the items in this category correctly was 31% and that of the Turkish students was 11%.

3.1.4. Students' Understanding of Relationship between Cell Divisions and Inheritance. The proportion of the English students stating that sex cells of an organism have haploid number of chromosomes and somatic cells have diploid number of chromosomes was 74% and that of the Turkish students was 57% (item (6)). In response to item (9) asking the characteristics of a cell whose chromosome formula is given, 40% of the English students and 50% of the Turkish students responded correctly. This is one of the two items (the other is item (3)) to which a higher proportion of Turkish students gave correct responses compared to the English students. The common feature of these two items is that the number of chromosomes in these items is displayed in the form of a chromosome formula. In item (11), participants are asked to give a reason why the number of chromosomes are the same in all somatic cells of an individual. The proportion of the English students stating that mitosis produces somatic cells with identical genes was 71% and that of the Turkish students was 56%. In item (12) relating to the relationships between cell divisions and inheritance, the proportion of the English students stating that, following the formation of sex cells through meiosis, sperm and egg cell come together to form a zygote and then zygote undergoes mitosis was 62% and that of the Turkish students was 46%. In this category where the correct response rates to the items are the highest for both the English and Turkish students, the proportion of the English students correctly responding to all the four items related to the relationships between cell divisions and inheritance was 22% and that of the Turkish students was 19%.

3.2. English and Turkish Students' Alternative Conceptions about Genetics Concepts. From the analysis of students' responses to the TGCT items, several alternative conceptions were identified that were held by at least 10% of the students. A value of 10% was chosen because a higher minimum value could possibly eliminate any valid alternative conceptions that may have been held by significant numbers of students [29]. English and Turkish students' levels of selecting statements based on known alternative conceptions are displayed in Table 3. Sixteen significant alternative conceptions were identified (reaching the 10% threshold in one or both of the samples) and grouped under the headings of gene, chromosome, relationships among gene, chromosome and DNA, and relationships between cell divisions and inheritance. Of these 16 alternative conceptions, eight reached the 10% threshold in both samples and the other eight only in one of the two samples.

3.2.1. Students' Alternative Conceptions of Gene Concept. The proportion of the English students suggesting that the genes

determining inherited characteristics are only found in sex cells was 16% and that of the Turkish students was 27%. As a reason for their responses, English and Turkish students stated that the genes are transferred to the offspring through sperm cell of the father and egg cell of the mother. In a similar manner, English and Turkish students specified that inherited characteristics are transferred to the offspring by sex chromosomes; hence, they stated that genes are carried in sex cells. While fewer than 10% of the English students suggested that the genes determining a characteristic are located only in tissues where they are expressed, it was seen that 17% of the Turkish students selected this reason for their response. The proportion of the Turkish students who suggested that the genes determining the eye colour are located only in sperm was 17% and that of English students was 6%. The reason of these students for their response was that X and Y chromosomes found in a sperm cell carry all the genes.

3.2.2. Students' Alternative Conceptions of Chromosome Concept. An alternative conception encountered in items (2) and (5) reemerged in item (8). Ten percent of the English students and 11% of the Turkish students stated that sex chromosomes are only found in sex cells. The most common alternative conception among both the English students (28%) and the Turkish students (36%) is that the chromosomes determining the sex of an individual are located only in sex cells. These students stated that as a sperm cell can carry X or Y chromosome and egg cell can carry only X chromosome chromosomes determining the sex can only be found in sex cells.

3.2.3. Students' Alternative Conceptions of Relationships among Gene, Chromosome, and DNA. Nineteen percent of the Turkish students suggested that DNA is made of the chromosomes and 15% of them suggested that chromosomes make up genes. 25% of both the English and Turkish students stated that chromosomes form DNA. These students remarked that the statement "there is DNA in the structure of a chromosome" is false. Another alternative conception seen in 6% of the English students but seen in 11% of the Turkish students is that gene contains chromosomes and DNA.

3.2.4. Students' Alternative Conceptions of Relationships between Cell Divisions and Inheritance. One of common alternative conceptions seen both in the English students (15%) and in the Turkish students (27%) is that the sperm cells of an individual have identical genes. Another common alternative conception is that somatic cells of an individual have different genes. The proportion of the English students stating that each somatic cell in the body carries genes different from each other was 14% and that of the Turkish students was 12%. Another alternative conception seen in fewer than 10% of the Turkish students but seen in 10% of the English students is that if the somatic cells did not undergo mitosis, the number of their chromosomes would be doubled. An alternative conception seen in 11% of the English students and 8% of the Turkish students is that zygote undergoes

TABLE 3: Students' alternative conceptions displayed in their understanding of fundamental genetics concepts.

Alternative conceptions	England %	Turkey %
Gene concept		
Genes that determine an individual's inherited characteristics are only found in sex cells. (Item (2))	**16**	**27**
The gene for eye colour is located in the iris because iris is the part of the eye responsible for eye colour. (Item (5))	(5)	**17**
The X and Y chromosomes, which are found in a sperm cell, carry all the genes. (Item (5))	(6)	**17**
Chromosome concept		
Sex chromosomes are only found in sex cells. (Item (8))	**10**	**11**
The chromosomes, which determine the sex of an organism, are located only in the sex cells because a sperm cell can carry X or Y chromosomes and an egg cell can carry only X chromosome. (Item (8))	**28**	**36**
Relationships among gene, chromosome, and DNA		
DNA is made of chromosomes. (Item (1))	(5)	**19**
Chromosomes make up genes. (Item (2))	(9)	**15**
Chromosomes form DNA. (Items (4))	**25**	**25**
Gene contains chromosomes and DNA. (Item (10))	(6)	**11**
Relationships between cell divisions and inheritance		
Sperm cells of an organism have identical genes. (Item (7))	**15**	**27**
Somatic cells of an individual have different genes. (Item (10))	**14**	**12**
If the somatic cells did not undergo mitosis, the number of their chromosomes would be doubled. (Item (11))	**10**	(7)
Zygote undergoes meiosis for reducing its number of chromosomes to half. (Item (12))	**11**	(8)
Sex cells form a zygote by the process of meiosis. (Item (12))	(7)	**18**
Inherited characteristics are carried only by sex chromosomes. (Items (2) and (13))	**23**	**26**
Parent's genes are transferred to the offspring by sex chromosomes of the father and the mother at fertilisation. (Item (13))	**21**	**17**

TABLE 4: Incorrect responses of students (more than 10%), which were not considered as alternative conception.

Incorrect responses	England	Turkey
(i) The chromosome number of an organism with the formula of $2n = 30 + XY$ is $n = 16$. (Item (3))	42	3
(ii) If $2n = 30 + XY$ then the chromosome number of this organism is $32 \times 2 = 64$. (Item (3))	10	1
(iii) Somatic cells have n chromosomes. (Item (7))	31	1
(iv) A zygote has 23 (22 + X) chromosomes. (Item (9))	16	1

meiosis for reducing its number of chromosomes to half. These students seem to think that zygote coming into being as a result of combination of sperm cell and egg cell needs to undergo meiosis and reduce its number of chromosomes to half. According to another alternative conception seen in 18% of the Turkish students and seen in 7% of the English students, sex cells form a zygote by the process of meiosis. It is seen that responses from both the English students (23%) and Turkish students (26%) suggest that they are of the opinion that inherited characteristics are carried only by sex chromosomes. Another common alternative conception seen both in the English students (21%) and in the Turkish students (17%) is that a parent's genes are transferred to the offspring by only the sex chromosomes of the father and mother at fertilisation.

3.3. *The Differences between English and Turkish Samples Related to the Nature of Curricula.* Some of the incorrect responses of students even though they were seen more than 10% of the student sample were not considered as alternative conceptions (see Table 4). Incorrect responses not regarded as alternative conception were seen in items in which the number of chromosomes is shown with a formula. In items where the number of chromosomes is displayed with formulas or symbols, while the incorrect response proportion of the Turkish students is not higher than 10%, the proportion of incorrect responses of the English students is considerably high and this appears as a notable finding. When the reason for this finding was sought, it was found that in the educational curriculum of the English students, haploid and diploid concepts are used for number of chromosomes but

symbols or formulas are not generally used to display them. On the other hand item (6) includes the proposition "sex cells of an organism have haploid number of chromosomes and somatic cells have diploid number of chromosomes," in which the English students achieved the highest proportion of correct response (74%). This finding supports that the instruction of the concepts of haploid and diploid number of chromosomes was successful for the English students. Therefore, incorrect responses of the English students related to the number of chromosomes were not considered as alternative conceptions. It could be understood that there are some differences in English and Turkish educational curricula in terms of displaying number of chromosomes with symbols or formulas.

Another difference between English and Turkish educational curricula related to genetics instruction is about the relationship between gene and DNA. In Turkish educational curriculum, gene is defined as a certain length of DNA and a DNA molecule contains many genes. In the English educational curriculum on the other hand, it is emphasized that genes are made up of DNA or DNA makes up genes. This is related to ontology of the concept of gene, and depending on the perspective adopted, both of the approaches to the explanation of the relationship between gene and DNA are feasible.

4. Conclusions and Discussion

In the present study looking at the English and Turkish students' understanding of genetics concepts, the findings show that there are some differences between the levels of understanding of the students while some alternative conceptions are adopted to a similar extent by both student groups. Out of 16 alternative conceptions represented by distractors commonly (i.e., at 10% incidence or greater) selected in the study, eight were commonly observed in both of the groups, two of them were only commonly seen in English students, and six of them were only commonly observed in Turkish students. In addition to the differences between proportions of alternative conceptions apparently held by the English and Turkish students, there are also significant differences between their levels of understanding the concepts.

In general, the results obtained from the administration of the TGCT reveal that the students of both countries have a limited understanding of the fundamental concepts of genetics. The possible highest score to be taken from the TGCT is 13 and the mean score of the English students is 6.7 and that of the Turkish students is 4.7. Only 3% of the English students correctly responded to all the items in the test and only 2% of the Turkish students could do so. The research looking at the students' understanding of genetics concepts in the literature has revealed similar findings and reports that students' understanding of genetics is poor [10], piecemeal, and disconnected [30]; moreover, there are some difficulties in explaining the relationships between the concepts [5, 14, 31, 32].

When the differences between the correct responses given to the items are examined, it is seen with the exception of two items (items (3) and (9)); the English students' proportions of correct responses to all the other items are higher than that of the Turkish students. The common feature of these two items is that the number of chromosomes is expressed with formulas. The reason why the English students gave fewer correct responses to these two items is that they are not generally familiar with showing the number of chromosomes with symbols, formulas, or equations. In the educational curriculum of the English students, haploid and diploid concepts are used for number of chromosomes but symbols or formulas are not used to show them; hence, the English students' had lower correct response proportion for these two items. One of the possible reasons for the English students to give more correct responses to all the other items is that the students of English sample have had one or two more years of biology education than the students of Turkish sample. In addition, English students comprise a selective sample, being those who have voluntarily chosen to follow an academic course in biology and been admitted to do so. For these reasons English students may have higher levels of motivation and interest and also more positive attitudes toward genetics. According to researchers [33], students' performances are influenced by their interest level and the importance of the subject matter for their future careers. So students of the English sample may have seen an important connection between their genetics courses and their future careers and this may have an effect on their approaches and attitudes, which led to high-performance. Moreover, while, in the English educational curriculum, genetics concepts are presented in relation to the themes of cell, cell divisions, and cellular control, in the Turkish educational curriculum, they are presented in an independent manner from each other and at different grade levels. Therefore, making connections between the concepts may be easier for the English students. This may also be one of the important reasons for the English students to demonstrate fewer alternative conceptions than the Turkish students. It may explain why Turkish students appeared to find it difficult to relate new concepts with their existing conceptual framework. Consequently this may impede meaningful learning and cause them to have numerous alternative conceptions. As suggested by Ausubel [21], one of the main factors determining whether learning material is potentially meaningful depends on the availability of the relevant content in the cognitive structure of the particular learner. Turkish students' limited understanding of fundamental genetics concepts such as gene and chromosome may result in failures to make appropriate links and impede understanding of relationships between genetics concepts and further related subjects. Additionally, uncontrolled variables which can affect understanding of genetics concepts, such as reasoning ability, learning approaches, and attitude toward genetics [33, 34] could differ in student samples. This may explain reasons for the differences between English and Turkish students' understanding of genetics concepts.

In relation to fundamental genetics concepts, there were 10 distractors indicating alternative conceptions commonly selected by the English students and there were 14 distractors indicating alternative conceptions commonly selected by

the Turkish students, and some of these alternative conceptions are common and some are different. Several common alternative conceptions are found to be related to each other and they indicate that in general students seem to think that inherited characteristics are carried by sex chromosomes, sex chromosomes are only found in sex cells, and accordingly, genes determining inherited characteristics are only found in sex cells. According to another common alternative conception supporting this result is that chromosomes determining the gender are only found in sex cells. Lewis et al. [4] concluded that many students believe that only some certain cells, particularly those found in reproduction system, contain genetic information. Moreover, in another study [5], they found that a large majority of students think that sex chromosomes are present only in sex cells or reproduction organs.

Responses reflecting another alternative conception related with the location of genes selected at notably higher level by the Turkish students than the English students. This alternative conception may stem from the idea that a gene determining any characteristic is found only in the cell, tissue, or organ having this characteristic. These students seem to believe that each cell contains genes specific to itself. In the related literature, it is reported that students think that cells contain only the genetic information they need to serve their functions [5, 35]. Another related alternative conception determined in this study shows similarity with the results of another study [36], which was concluded that most students think that each type of cell contains different genes. As stated by Hackling and Treagust [36], one of the important reasons for these alternative conceptions is a lack of understanding of the role played by mitosis in growth which ensures that all the new body cells produced during the growth of the individual have the same genes as the zygote they derive from.

Two alternative conceptions reflecting responses selected at higher level by the English students than the Turkish students are related to mitosis and meiosis. These findings suggest that some of the students are confused about in which cells cell divisions occur. In addition it was found that some of the students cannot differentiate the processes of reproduction and cell divisions from each other or at least are confused over the associated terminology. According to the results of another study [6] conducted with 14–16-year-old students as they near the end of their compulsory science education in the UK, meiosis is associated with reproduction and confused with fertilisation. Parallel to these results, in the present study another commonly selected response reflecting an alternative conception is related with transfer of parental genes to the offspring. The reason for students to state that parental genes are transferred into the offspring by sex chromosomes through the combination of sex cells seems to be related with students' another alternative conception, which refers to the fact that inherited characteristics are carried only by sex chromosomes.

The alternative conceptions seen in the category of relationships among gene, chromosome, and DNA are mostly observed in the Turkish students. According to the related findings, some students confuse the concepts of gene, chromosome, and DNA with each other and hence, they cannot explain the relationships between these concepts correctly. One of the possible reasons for this finding may be the teaching of these concepts under different topics in the educational curriculum. Therefore, the students have difficulties in establishing relationships among the concepts they learn under different topics. Response indicating a related common alternative conception "chromosomes form DNA" was selected by the same proportion of English and Turkish students (25%). This result supports the idea that many students cannot accurately and correctly understand the structures and relationships related to gene, chromosome, and DNA, which are the fundamental concepts of genetics.

In general, results of the present study show that there are some differences between the English students' and Turkish students' understanding of fundamental concepts of genetics; however, there are some similarities between the alternative conceptions apparently held by these two groups of students. Though the common alternative conceptions seen in both of the groups indicate that the students understand the concepts regardless of contextual factors, different proportions of the common alternative conceptions show that conceptualisations take place under the influence of different educational contexts. It is understood that differentiation in levels of understanding and alternative conceptions is related to the content and sequence of the topic presentation in the educational curricula. Though there is a considerable overlap in terms of the content of the educational curricula related to fundamental concepts of genetics, there are some differences in detail and this may have led to differentiation between the groups.

5. Educational Implications

In the present study it was found that both the English students and Turkish students have limited understanding of the fundamental concepts of genetics and their responses to the instrument suggest they have some common alternative conceptions. Lack of complete and accurate understanding of the fundamental concepts of genetics imposes substantial limitations on the understanding of the further topics related genetics subjects. Thus, it is of great importance to emphasize teaching of the fundamental concepts and improving of erroneous and inadequate understanding. The alternative conceptions held by the students in the present study were found to stem from the lack of the complete understanding of the relationships among the concepts. There is a large number of studies in science education research reporting some strategies facilitating the establishment of relationships between concepts [37]. Among these, there are some studies showing that concept maps and drawings enhance the understanding of the relationships among the genetics concepts [13, 38, 39].

Another result of the present study elicited with the administration of TGCT is that the high proportion of correct response in the first tier of the test items decreased to a great extent in the second tier where the reasons for their responses are asked. This result indicates that the students learn without an adequate understanding or they

learn just by memorising. For achieving meaningful learning, visualization of the abstract concepts can be useful. It has been demonstrated that models, analogies, and simulations enhance the understanding of abstract concepts [40–43].

In the present study, it was found that, besides the similarities among the understanding levels and alternative conceptions of the English and Turkish students, there are also some differences. Taber [24] states that if different frequencies of alternative conceptions are found in different contexts, then it may be that there is a significant influence of contextual factors. The basic reason for students to have different levels of understanding and different alternative conceptions is seen to be the differences in the content of educational curricula and sequence of the presentation of topics. As stated by Tan et al. [44], differences in curriculum, sequence of teaching, and teaching approaches may be important factors in students' learning of the intended target knowledge. The results attained from this study provide some preliminary suggestions for instruction of fundamental concepts of genetics that should be taught in association with related topics such as cell, cell divisions, and cellular control in curriculum. Moreover, when these fundamental concepts are revisited at higher educational levels, the prior knowledge of students should be activated so that they can create connections between preinformation and new information.

The results of the present study may contribute to the efforts to be made to reduce the levels of alternative conceptions held about genetics concepts. Also the study can be a useful source for future researchers interested in students' understanding of genetics phenomena. The TGCT administered to the English and Turkish students can be administered to other samples, including students from other countries, which may provide more comprehensive and generalisable results.

Appendix

Two-Tier Genetics Concepts Test

(1) Where are the chromosomes found in the cell?

   (a) in DNA
   (b) in Genes
   (c) in the Nucleus

   Which of the following is the reason of your answer?

   (a) DNA is made of chromosomes.
   (b) Chromatin strands, which make up chromosomes, are found in the nucleus.
   (c) Genes are made of chromosomes.
   (d) Chromosomes make up DNA, which is found in genes.
   (e) Chromosomes, which carry genes, are located in DNA.

(2) Which cells of an individual contain the genes that determine his/her inherited characteristics?

   (a) Sex cells/gametes
   (b) Brain cells
   (c) All cells

   Which of the following is the reason of your answer?

   (a) Chromosomes, which make up genes, are found in all cells.
   (b) Genes are found in sex cells as the parental genes are carried by sperm of the male and eggs (ova) of the female.
   (c) Inherited characteristics are carried in sex cells as they are transferred to offspring by sex chromosomes.
   (d) Chromosomes, which are found in all cells, contain genes which determine our inherited characteristics.
   (e) Everything is controlled by the brain.

(3) What is the chromosome number of an organism with the formula of $2n = 30 + XY$?

   (a) 64
   (b) 32
   (c) 16

   Which of the following is the reason of your answer?

   (a) Because the chromosome number of an organism is n; and if $2n = 32$, than $n = 16$.
   (b) 30 + XY come from the father. 30 + XX come from the mother. In total this gives 64 chromosomes.
   (c) The chromosome number of an organism is equal to the number of sex chromosomes and somatic chromosomes added together.
   (d) If $2n = 30 + 2$ then the chromosome number of this organism is $32 \times 2 = 64$.
   (e) The number of somatic chromosomes is 2 and the number of sex chromosomes is 30. The total number of chromosomes is 32.

(4) Which statement about chromosomes is incorrect?

   (a) Sex chromosomes are present only in sex cells.
   (b) There are lots of genes located on a chromosome.
   (c) There is DNA in the structure of a chromosome.

   Which of the following is the reason of your answer?

   (a) Sex chromosomes are present in all cells.
   (b) A gene is formed when chromosomes are merged.
   (c) Chromosomes form DNA.
   (d) Chromosomes are located on genes because the genes are bigger.
   (e) Sex chromosomes exist only in somatic cells.

(5) Where is the gene for eye colour located?

    (a) In all the cells

    (b) In the iris of the eye

    (c) In sperm

Which of the following is the reason of your answer?

    (a) Genes are only located in tissues where they are expressed.

    (b) The X and Y chromosomes, which are found in a sperm cell, carry all the genes.

    (c) All genes are present in all cells.

    (d) Different parts of a body have their own specific genes.

    (e) The iris is the part of the eye responsible for eye colour.

(6) How many chromosomes are there in a nerve cell of an organism which has 16 chromosomes in its egg cell (ovum)?

    (a) 32

    (b) 16

    (c) 8

Which of the following is the reason of your answer?

    (a) A somatic cell has twice the number of chromosomes as a sex cell.

    (b) The number of chromosomes is the same in each cell of an organism.

    (c) Egg cells include $2n$ chromosomes and somatic cells include n chromosomes.

    (d) Sex cells undergo meiosis and the number of chromosomes is halved. Because of this, a nerve cell carries 8 chromosomes.

    (e) Both an ovum and a nerve cell have n chromosomes.

(7) Which of the following pairs of cells have identical genetic information?

    (a) Sperm cell – Brain cell

    (b) Eye cell – Skin cell

    (c) Sperm cell – Sperm cell

Which of the following is the reason of your answer?

    (a) Eye and skin cells have n chromosomes, which are the same in both types of cells.

    (b) Genetic information in sperm cells is transferred to brain cells.

    (c) Sperm cells of an organism have identical genes.

    (d) The chromosomes in sex cells are always the same.

    (e) Identical genes are present in all somatic cells of an organism.

(8) Where are the chromosomes located which determine the sex of an organism?

    (a) Only in the ovaries and testes

    (b) Only in the sperm and egg cells

    (c) In all the cells

Which of the following is the reason of your answer?

    (a) A sperm cell can carry X or Y chromosomes, an egg cell can carry only X chromosomes.

    (b) Different organs have their own specific genes and chromosomes.

    (c) If the reproductive organ of an individual is a testicle than this individual is a male, if its reproductive organ is an ovary than this individual is a female.

    (d) Sex chromosomes are only found in sex cells.

    (e) Every cell contains every chromosome.

(9) Which of the following could be a cell of a human with 22 + X?

    (a) A somatic cell of a female

    (b) Sperm cell

    (c) Zygote

Which of the following is the reason of your answer?

    (a) Chromosome X represents female.

    (b) It can only be found in a sex cell of a male or a female.

    (c) A zygote contains both somatic and sex chromosomes.

    (d) A zygote has 23 chromosomes.

    (e) 22 represents somatic chromosomes, so 22 + X can be found in a somatic cell of a female.

(10) (I) Genes are located on chromosomes.

(II) Genes are made up of DNA.

(III) All somatic cells have the same genes.

Which of the sentences above are correct?

    (a) Only (III)

    (b) (I) and (II)

    (c) (I)-(II)-(III)

Which of the following is the reason of your answer?

    (a) Chromosomes are located on genes, which are the same in every cell in the body.

    (b) Chromosomes of a somatic cell carry different genes according to the function of a cell.

    (c) Genes, which are made up of DNA, are located on chromosomes and are different from each other in each cell in the body.

(d) Genes, which are made up of DNA, are located on chromosomes and are the same in all somatic cells.

(e) Chromosomes and DNA of genes are the same in all somatic cells of an individual.

(11) The number of chromosomes are the same in all somatic cells of an individual. Which of the following processes are responsible?

(a) Meiosis

(b) Mitosis

(c) Mutation

Which of the following is the reason of your answer?

(a) Through meiosis, the chromosome number of sex cells (n) is doubled to make an individual with $2n$ chromosomes, again.

(b) If the somatic cells did not undergo mitosis, the number of their chromosomes would be doubled.

(c) Mutations occur in order to stop the number of cells increasing and increasing.

(d) In meiosis, the number of chromosomes is kept constant.

(e) Mitosis produces somatic cells with identical genes.

(12) How does an offspring come into being?

(I) Sperm and an egg cell come together to form a zygote.

(II) Zygote undergoes meiosis.

(III) Sex cells are formed by meiosis.

(IV) Sperm and egg cells undergo mitosis.

(V) Zygote undergoes mitosis.

Which of the following order is correct?

(a) (III)-(I)-(II)

(b) (III)-(I)-(V)

(c) (IV)-(I)-(III)

Which of the following is the reason of your answer?

(a) A sperm and an egg cell, which are formed by meiosis, come together to produce a zygote. Then a zygote reduces its chromosome number to half by the process of meiosis.

(b) Sex cells multiply by mitosis, but they are formed by meiosis.

(c) Sex cells form a zygote by the process of meiosis, and the zygote undergoes mitosis.

(d) Sperm and egg cells, are formed by meiosis and then they come together to form a zygote. The zygote undergoes mitosis for further development.

(e) Firstly, sperm and egg cells are multiplied by meiosis. They then come together to form a zygote. The zygote undergoes meiosis to form the sex cells of the offspring.

(13) How are parent's genes transferred to the offspring?

(a) By XY chromosomes in the father's sperm cell and somatic chromosomes of mother.

(b) By sex chromosomes of the father and the mother.

(c) By both sex chromosomes and somatic chromosomes of the father and the mother.

Which of the following is the reason of your answer?

(a) Inherited characteristics are only carried by sex chromosomes.

(b) Genes of the mother are transferred to the zygote by her somatic chromosomes, as the offspring grows in her body, and the genes of the father are transferred by sperm cells.

(c) Sex cells carry both sex chromosomes and somatic chromosomes.

(d) Sex chromosomes of the father and the mother are transferred to the offspring at fertilisation.

(e) Chromosomes of X or Y come from the father to form the sex cells of the offspring and somatic chromosomes of the mother come to form the body's cells.

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

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