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Problem Solving in Genetics: Conceptual and Procedural Difficulties

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Abstract

The purpose of this study was to explore prospective biology teachers' understandings of fundamental genetics concepts and the association between misconceptions and genetics problem solving abilities. Specifically, the study describes conceptual and procedural difficulties which influence prospective biology teachers' genetics problem solving abilities. Case study methods were utilized in this study. Total of 70 prospective biology teachers participated in this study. The data sources included genetics concept tests (GBT) and semi-structured interviews. Genetics concept tests were administered to all of the participants. Six participants were selected by purposeful sampling for semi-structured interviews. The results of the study showed that prospective biology teachers had incomplete understandings and several alternative conceptions of Mendelian genetics. Although they were able to describe some concepts, they frequently failed to apply them in problem solving situations. In many cases mechanical application of common problem solving strategies were observed without comprehensive conceptual understanding. The participants that demonstrated behaviors which require metacognitive strategies and higher order thinking skills such as constructing hypothesis, data, and end-means analysis were more successful in genetics problem solving. Some of the participants who were successful in cause-effect type problems had difficulties in end-means type of problems.

Key Words

Genetics Learning, Problem Solving in Genetics, Biology Teacher Education.

Genetics, the central point of developments in the field of biology, is a particularly difficult subject for teachers and students; since it involves relations between the events of different levels of biological organization. Additionally, genetics attempts to define directly unobservable probabilities that are happening too fast or too slow and too small or too large in scale. Misconceptions in genetics are encountered and reported frequently (Atılboz, 2004; Bahar, Johnstone, & Hansell, 1999; Bahar, Johnstone, & Sutcliffe, 1999; Dikmenli, 2010; Kinfield, 1991a, 1991b; Longden, 1982; Öztas, Özay, & Öztas, 2003; Steawart & Dale, 1989; Steawart, Hafner, & Dale, 1990; Şahin & Parim, 2002; Tekkaya, Çapa, & Yilmaz, 2000; Temelli, 2006). It is desirable for prospective biology teachers to engage with scientific reasoning strategies such as data interpretation, prediction, and hypothesis testing while trying to explain biological processes and events. Scientific reasoning and sense making activities allow students to develop in-depth understanding of the subject (Cooper, Hanmer, & Cerbin, 2006). The purpose of this study was to investigate prospective biology teachers' understanding of basic Mendelian genetic concepts and to examine the conceptual and procedural challenges they encounter during the process of problem-solving in genetics.

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Misconceptions and Sources of Misconceptions

Misconceptions are defined as conceptual patterns that deviate from the meanings widely accepted by the scientific community (Bahar, 2003; Clement, 1982; Smith, 1989). Misconceptions are resistant and unlikely to change with traditional teaching methods. Misconceptions usually arise from students' prior knowledge and everyday experiences (Halloun & Hestenes, 1985). Students emotionally and intellectually depend on their misconceptions since they constitute them actively consuming energy in time. However, misconceptions do not only arise from primitive worldviews or daily life experiences but also as a result of both formal and informal education (Barras, 1984; Gniffithi & Grant, 1985; Kesercioğlu & Dalkıran, 2006; Smith, 1989). For example, the textbooks used in formal education are considered to be important sources of misconceptions (Dikmenli & Çardak, 2004; Dikmenli, Çardak, & Öztaş, 2009). Teachers have a critical influence on students' knowledge, interest, understandings, and misconceptions. Shaw, Horne, Zhang and Boughman (2008) observed and reported that students had knowledge, personal interests, and bias as their biology teachers. They also identified major misconceptions in 55.6% of students' writings about genetics even after corrections performed by their biology teachers (Shaw et al., 2008). Azar (2003) reported that prospective teachers did not see themselves as sufficiently capable teachers to conduct conceptual teaching for their students. Longden (1982) stressed that students' misconceptions about genetics in fact is due and related to the nature of the genetic issues themselves.

Problem and Problem Solving

Although the concept of problem has very different meanings in the literature, overall it can be evaluated as a situation which presents a barrier for a problem solver and its successful solution requires finding the appropriate method and converting the method into a skill (Altun, 2000; Kalaycı, 2001). On the other hand, problem solving can be defined as an activity that requires both subject matter knowledge and selection of appropriate cognitive strategies to find means in order to reach the desired outcomes (Senemoğlu, 2005). In an attempt to explain the process of problem solving, Kneeland (2001) proposed an iterative model. Phases of the iterative model include (*a*) understanding the problem, (*b*) gathering the necessary information, (*c*) searching for the root of the problem, (*d*) developing solutions, (*e*) deciding on the best pathway, and (*f*) solving the problem. Iteration continues until the problem is solved. Adair (2000) proposed a model that combines the decision-making and problem-solving processes. According to Adair (2000), thinking and the problem solving is a multi-stage and a complex process; therefore he proposed a bridge model stating that in order to understand where the individual is in a problem-solving and decision-making process a simple bridge should be established between the stages of the process. Lumsdaine and Lumsdaine (1995) classified the problem-solving methods used by people in daily life as trial and error, conjecture, open-ended inquiry (unguided experimentation), intuition, and scientific method which is rarely used in education. Orcajo and Aznar (2005) classified the types of genetic problems, used during genetics lectures to students as an example, into two groups: (*1*) cause-effect problems (closed problems) and (*2*) effect-cause problems (open problems). Comparing two types of the problems, Steawart (1983) argued that effect-cause problems work better than cause-effect problems; stating that since cause-effect problems can be solved by using a set of algorithms such problems in high school textbooks cannot help students to develop conceptual understandings or teachers to measure conceptual knowledge of the students.

Purpose

Understanding events and phenomena are very similar cognitive concepts to problem solving (Stewart & Hafner, 1994). Problem solving ability is a high level cognitive process which can be enhanced with education (Altun, 2000; Kneeland, 2001; Senemoğlu, 2005). The purpose of this study was to explore prospective biology teachers' understandings of basic Mendelian genetics concepts and identify conceptual and procedural challenges they grapple with during solving genetics problems which require high-level cognitive abilities such as hypothesis testing, data collection, analysis, and manipulation. In Turkey, research about problem solving and genetics misconceptions are particularly concentrated in primary and secondary education (Altun, 2000; Atılboz, 2004; Gürdal, Bayram, & Sökmen, 1999; Kasap, 1997; Nakiboğlu & Kalın, 2003; Şahin & Parim, 2002; Tatar & Cansüngü Koray, 2005); therefore undergraduate level studies are needed. The research questions of this study were: (*1*) What common misconceptions about basic Mendelian genetics are held by prospective biology teachers? (*2*) What kind of conceptual and procedural difficulties do prospective biology teachers grapple with during problem

Table 2.
The Number of Participants Who Failed to Proceed From Each Solution Steps of Second Item (N=70)

	Omitted	Completely Correct	Solution Steps							
			2.a	2.b	2.c	2.d	2.e	2.f	2.g	2.h
4th Year (n=38)	13	0	9	0	0	2	0	0	13	1
5th Year (n=32)	3	6	6	0	0	9	0	0	2	6

solving in genetics? In order to answer primary research questions two sub-questions were raised: (*a*) What is the relationship between prospective biology teachers' conceptual knowledge level and their success in problem solving process? (*b*) What kind of difficulties about general problem solving procedures do prospective biology teachers encounter during problem solving in genetics?

Method

Research Design

Case study research design is one of the qualitative research traditions and it was employed in this study. The research participants were prospective biology teachers who were in their fourth and fifth year and enrolled in Marmara University, Atatürk Faculty of Education during 2008-2009 academic years. There were total of 70 (18 male, 52 female) participants, all of whom had taken genetics course in previous years. In first stage of the study Genetics Achievement Test (Appendix 1) was administered to all of the participants and tests were analyzed with document content analysis technique. In order to use in document analysis solution diagrams for each question were developed (Appendix 2). The results of document analysis were used to purposefully select the participants for semi-structured interviews which are the primary data source in this study. Genetics Achievement Test results were classified in three groups, namely, low, average, and high ability groups. Using maximum diversity sampling method (Patton, 1990) two participants, one fourth and one fifth year students were selected from each group. Finally six volunteer participants were identified for semi-structured interviews. Interviews were audio and video recorded. Both Genetics Achievement Test and semi-structured interview protocol was pilot tested prior to use in this study.

Process of Data Analysis

The solution flow diagrams were used in analysis of Genetics Achievement Test. Each step in solution diagram is scored 1 if correct and 0 if omitted or wrong. As a result, a participant could get total score of 5 in question one, 8 in question two, 7 in question three, and 4 in question four; adding up to the highest score of 23. Achievement tests were also used in semi-structured interviews and selected participants were asked to delineate their answers.

Semi-structured interviews were transcribed and analyzed with constant comparative method. The data was imported in qualitative data analysis software, Nvivo. Open and axial coding performed by two researchers independently and inter-coder agreement was achieved through discussions in meetings. Interview data was triangulated with Genetics Achievement Test document analysis. Inferences from coding and scoring tests were confirmed and supported through member check method in individual interviews. In order to elucidate thinking and reasoning patterns of the participants open-ended questions from previously answered tests utilized and participants were encouraged to be vocal and provide reasons for their actions during the problem solving tasks.

Results

Conceptual understanding of fundamental genetics concepts is a prerequisite requirement for successful problem solving in genetics. The most problematic concept, among prospective biology teachers, was the concept of "allele". Most of the participants had misconceptions, inconsistent or partial understandings of the allele concept. The participants had a difficult time in defining the concept and they usually tried to give examples and explain the manifestations of the alleles instead of describing the concept. The analysis of second question in achievement test reflects the participants' lack of conceptual understandings of linked genes, cross-over, phenotype and genotype ratios and ability of developing inheritance model. The number of successful problem solvers for each step of the question is shown in Table 2.

The reason for prospective biology teachers failure in steps 2.a and 2.g has to do with incorrect or incomplete understandings of allele concept. Similarly, prospective biology teachers demonstrated incomplete, inconsistent or partial understandings of fundamental Mendelian concepts such as dominant and recessive trait, homozygous and heterozygous individuals. Gene concept was usually well understood however distinction between "gene" and "allele" was not clear for most of them as they attributed simple dominance or recessiveness to genes instead of alleles. Other problematic concepts included epistasis, co-dominance and incomplete dominance. Epistasis was usually confused with cases of multiple alleles. The participant could not easily differentiate interactions between different genes and between the different alleles of the one gene. For example, the failure to solve the fourth problem in achievement test can be attributed the lack of understanding of concept of recessiveness. Table 3 presents the number of successful participants for each steps of solutio0n.

Table 3.
The Number of Participants Who Failed to Proceed From Each Solution Steps of Fourth Item (N=70)

	Omitted	Completely Correct	Solution Steps		
			4.a	4.b	4.c
4th Year (n=38)	6	0	32	0	0
5th Year (n=32)	7	6	17	0	2

The most common hindrance that prevented the participants from proceeding to next step in this question was the lack of conceptual understandings of concepts of recessiveness, pure breed, and heterozygous. Most of the participants failed to assign correct notations to represent genotypes in order to identify possible gamete types and perform correct crosses. One striking finding was that although most of the participants were able to give the textbook definition of the alleles; they could not able to visualize the locations of the alleles during meiosis. The role and process of meiosis in gamete formation should be emphasized and the mechanism of crossing-over and its' relationship to gene linkage and genetic variation via recombination should clearly be made apparent.

Successful problem solving in genetics requires knowledge on subject area specific problem solving procedures as well as general problem solving abilities. For example, identification of possible gamete formations using the principle of independent assortment for unlinked genes is important in performing crosses and coming up with correct genotype and phenotype ratios in different generations. Since Genetics Achievements Test included effect-cause type of problems, the participants were expected to utilize probabilistic thinking and inquire about several different scenarios which may yield the same results and choose the most likely model that was consistent with Mendelian modes of inheritance. However, the participants failed to employ critical inquiry in evaluating available information and haphazardly used ratios and algorithms that are commonly associated with monohybrid or dihybrid crosses instead. Successful problem solvers demonstrated two distinct behavior worth to mention: they established a cause analysis procedure in which they specify the reasons for using any given method in each step of the solution; and they confirm their result, going back and forth in solution procedure trying to revise their approach when necessary. Understanding the problem correctly, redefining it, and determining important information by distinguishing it from unnecessary information plays a key role in problem solving process. Successful problem solvers also tried to restate the problem in an effort to understand the situation doing an end-means analysis before attempting to propose any method for solution.

Document analysis revealed that the participants rarely used metacognitive strategies such as reflection to evaluate their own problem solving process. Successful problem solvers utilized and integrated both conceptual and procedural knowledge of genetics. Especially, effect-cause problems necessitate prediction and forming hypothesis followed by hypothesis testing which provides a context where problem solver could formulate conceptual knowledge into researchable ideas, investigate ideas through manipulation, prediction, and observation, and evaluate ideas in the light of evidence.

Discussion

The participants who achieved the conceptual understanding not only were able to describe the concepts correctly but also able to explore these concepts in different problem situations and use them in suitable places in the process of problem solving. Bozkurt (2010) reported that students commonly failed to apply concepts in problem situation due to rote memorization. The results of this study show that prospective biology teachers have inconsistent and incomplete understandings and misconceptions of several basic Mendelian genetic concepts.

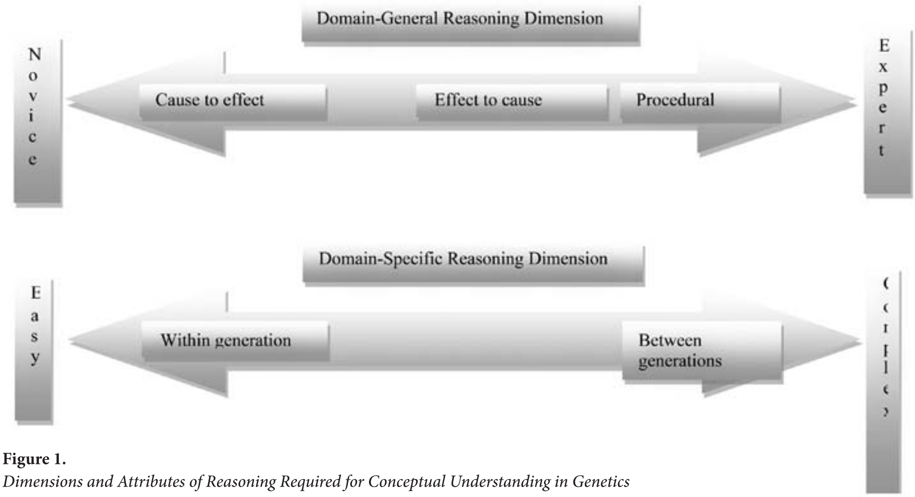

Figure 1.
Dimensions and Attributes of Reasoning Required for Conceptual Understanding in Genetics

Although they were able to describe concepts verbally; they failed to utilize them in problem solving situations. This is a clear indication of poor conceptual understanding. The results of this study supported findings that reported by Atılboz (2004), Dikmenli (2010), and Dikmenli, Çardak, and Kıray (2011), Dikmenli, Türkmen, Çardak, and Kurt (2005), Kindfield (1991a; 1991b), Longden (1982), Steawart and Dale (1989), Steawart et al., (1990), Şahin and Parim (2002), Tekkaya et al, (2000), Temelli, (2006). Similar to Orcajo and Aznar (2005) study, the problematic understandings of the location genetic information and the sequence of alleles on chromosomes have emerged in this study, too. Sağlam, Altun, and Aşkar (2009) explored problem-solving strategies of prospective mathematics teachers in computer algebra systems environment and reported similar results that prospective teachers adapted entirely opposite course of actions than what they learned in class when confronted with an error. It is evident that the prospective teachers' algorithmic knowledge of predefined genetics ratios and models does not help them to solve effect-cause type of problems. Traditionally, genetics courses are taught in an algorithmic-intensive way (Steawart, 1983) and such instruction is unlikely to support meaningful and conceptual learning (Stewart & Dale, 1989; Stewart et al., 1990). When encountered with unfamiliar type of problems participants behave inconsistently and could not finish the solutşion even when they were in the right track, additionally they used some previously mastered concepts in a different and wrong ways. Delice and Yilmaz (2009) investigated the effect of students' epistemological beliefs on their problem-solving abilities and reported that when the solution result is not familiar to students; they think solution is wrong even if they have solved the question correctly.

It is concluded that conceptual learning in genetics be possible through developing reasoning in two related but different dimensions. The first dimension requires cause-effect, effect-cause, and procedural reasoning; namely, "Domain-General Reasoning", and the second dimension requires reasoning within a generation and between generations; namely "Domain-Specific Reasoning". Reasoning dimensions that are necessary for conceptual genetic understanding and their characteristics are shown in Figure 1. In general, within generation reasoning is easier than between generation reasoning and cause-effect (from genotype to phenotype) reasoning is easier that effect-cause (from phenotype to genotype) reasoning (Stewart & Hafner, 1994). Similarly, effect-cause reasoning is easier than procedural reasoning (Kindfield, 1994a, 1994b). Participants were mostly challenged in problems that required both between generation and effect-cause reasoning.

Since, in order to achieve conceptual understanding and master problem solving procedures, students must have sound understandings of the process of gamete formation, independent assortments of the chromosomes, and crossing-over meiosis should be the first topic of introduction to genetics.

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