Difficulties in Genetics Problem Solving

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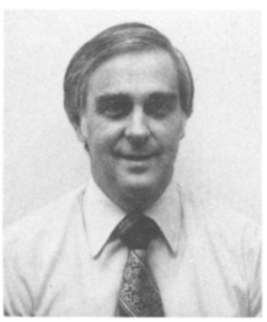

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The Center for Educational Research and Evaluation received an NSF grant under the Research in Science Education (RISE) program to conduct an expert-novice study of problem solving in genetics. Three different types of genetics problems were used in the study—a monohybrid cross, a codominance problem, and a problem with sex-linked inheritance. High school students were asked to solve these problems in a "think-out-loud" mode. Each problem-solving session was recorded on audio tape. Thirty junior or senior students in one Colorado high school who had previously completed a sophomore-level biology course were the subjects of the study.

While analyzing the typed transcripts of the problem-solving sessions, and the worksheets used by the students, some common patterns began to emerge. Although these common patterns did not relate specifically to the goals of the study, they did provide insight into problem-solving methodology and seemed important and worthy of reporting. It should be noted that this is not an attempt to generalize conclusions to the population of high school biology students. The results apply only to the group within this study. However, correspondence with colleagues at the University of Wisconsin and at West Virginia University indicate that students' problem solving in genetics at those institutions is yielding similar results.

One of the major difficulties encountered by the 30 students was understanding the concept that the pairs of alleles in an offspring are the result of transmission of one allele from each of the parents of the offspring. More specifically, the students experience difficulty in associating the alleles with chromosomes and chromosome behavior and the segregation and random assortment during the first division of meiosis. While constructing Punnett squares, students would commonly assign two alleles to each parent for an F_1 trait. This error was manifested in the production of a Punnett square similar to that in figure 1. This resulted in offspring with four alleles for each trait. Only 6 of 30 students (20%) accurately described the parental source of each allele in a pair of alleles for normal vision (M) and myopia (m).

	Mm	Mm
Mm	MmMm	MmMm
Mm	Mm	Mm

FIGURE 1. Punnett square illustrating a common student error.

The codominance problem consisted of several questions relating to a pedigree chart showing inheritance of A, B, and O blood groups in humans. The same dif-

TABLE 1. Frequencies of Successful and Unsuccessful Solutions With Three Types of Genetics Problems

	Problem Type		
Problem-Solving	*Monohybrid Cross*	*Codominance*	*Sex-linked*
Successful	6	12	19
Unsuccessful	24	18	11

$x^2_{2d.f.} = 11.66$ ($P<.01$)

ficulty was encountered by the students not realizing the need for reduction division and the need for only one allele from each parent.

One difference did emerge: 12 of 30 students (40%) were successful in correctly assigning one allele to each parent for the trait. The same type of difficulty emerged for unsuccessful students while constructing the Punnett squares—not identifying the parents as sources for single alleles.

The sex-linked problem consisted of several questions relating to a pedigree chart showing inheritance of color-blindness. In this instance, somewhat surprisingly, 19 of 30 students (63%) correctly identified the individual parents as probable sources of single alleles for the trait. All students used the symbol X for the X chromosome in which the alleles for normal and color-blind vision are carried. The students' verbal descriptions of the inheritance patterns were more clearly stated using the chromosome as the carrier for the alleles than was noted in either of the two earlier problems.

The frequencies of successful and unsuccessful solutions were entered into a frequency table and the chi-square technique was used to analyze the data. The results indicated significant differences at the .01 level (see table 1).

A review of the 1970 and 1975 National Assessment of Educational Progress (NAEP) reports revealed that no genetics test items had been released for 17-year-old students. However, the 1970 results for young adults support the findings reported here. Ninety-one percent of young adults knew that the sex of a human baby is determined by chromosomes. Thirty-one percent of the young adults could correctly solve a human blood type problem; 50% reported that they did not know how to solve the blood type problem. Forty percent of the 30 Colorado high school students who were interviewed in this study could solve a blood type problem. This compares favorably with the 31% reported in the National Assessment.

Because of the nature of this preliminary study there are probably many hypotheses that could explain the results obtained. For example, it is possible that practice in solving problems increased the accuracy of identifying the source of alleles as we proceeded through the sessions. Other hypotheses exist but will not be mentioned here.

After discussing these results with colleagues having many years of high school genetics teaching experience, the following possible explanation is offered. Students can explain, with relative ease, the parental source of the X and Y chromosomes. In fact, sex determination seems to be an inherently interesting topic for students. Alleles that are "tied to" the X chromosome are easily traced to the mother, in the case of a boy, or to the mother and father (one from each) in the case of a girl.

This possible explanation leads logically to a hypothesis concerning a new teaching sequence: if meiosis, sex determination by chromosomes, and sex-linked characteristics were taught back-to-back before other concepts, then students would be more proficient in tracing alleles back to parents. Some elaboration is in order. As the two divisions of meiosis are discussed, genes or alleles should be identified on the chromosomes, especially during the first meiotic division. Segregation and random assortment should be treated concurrently with meiosis, using hypothetical alleles or genes on each chromosome. Sex determination by X and Y chromosomes follows logically from meiosis. Punnett squares could be introduced together with probabilities for having male and female children. Next, a sex-linked trait such as colorblindness or hemophilia could be introduced and discussed. The alleles should be traced through meiosis to the F_1 generation. At this point, the standard terminology usually associated with Mendel's pea plants could be introduced and discussed—dominant, recessive, homozygous, heterozygous, genotype, phenotype, etc.

Returning to a more classical approach, analyzing and explaining Mendel's results could then reinforce what has been taught by the human examples. Instruction in other topics within genetics could then proceed as usual.

Table 2 summarizes a traditional and the proposed new teaching sequence.

It is hypothesized that this proposed teaching sequence could clear up some of the confusion that students have about genetics. A well-controlled testing situation should offer an answer to this hypothesis.

Returning to the original problem of making ties between sources of alleles and meiosis, one wonders why it is so difficult. An examination of most of the lead-

TABLE 2. Two Contrasting Genetics Teaching Sequences

Traditional Sequence	*Proposed Sequence*
1. Meiosis (without genes in diagrams, usually in a separate chapter, and little or no emphasis on chromosome behavior)	1. Meiosis (include genes in diagrams and emphasize chromosome behavior during first meiotic division)
2. Mendel's Pea Experiments — genes — dominance — recessiveness — segregation — independent assortment — genotype — phenotype — homozygous — heterozygous — alleles — Punnett squares	2. Sex Chromosomes—Human (show genes in diagrams—trace back to meiosis)
3. Monohybrid Cross	3. Sex Determination—Humans (show genes on diagrams—trace back to meiosis)
4. Dihybrid Cross	4. Sex-linked Traits—Humans — reemphasize genes on chromosomes—trace back to meiosis) — segregation — random assortment — dominance — recessiveness — genotype — phenotype — homozygous — heterozygous — alleles — Punnett squares
5. Incomplete Dominance (Codominance)	5. Monohybrid Cross—Humans
6. Sex Chromosomes	6. Dihybrid Cross—Humans
7. Sex Determination	7. Codominance—Humans
8. Sex-linked Traits	8. Mendel's Pea Experiments—bring in history of development of terminology

ing biology books yielded a possible answer. Most treat meiosis in isolation from any genetics material that could help students make the connection. Meiosis preceded genetics in all of the texts examined. Meiosis was even treated in a separate chapter from genetics in most of the texts. After meiosis, most texts begin genetics with a discussion of Mendel's peas without ever bridging the gap between meiosis and genetics. If teachers teach the material in the same manner in which it is presented in texts, this could lead to the confusion.

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biological structure is desired, the right hemisphere should be activated.

The brain can be monitored in another way that has great potential for extending knowledge about students' interests. A technique called the "evoked-potential technique" (EP) measures certain brain waves produced by a stimulus. It could be used to measure how interested a student is in a laboratory investigation, microscope slide, teaching chart, or scientific idea.

Learning is a complex process—likely one of the most complex happenings on our planet. As learning takes place, a myriad of chemical and electrical changes pervade the learner's body. Through biotechnology, knowledge gained about learning's associated physiological changes may revolutionize our techniques for research in science education. The time for that revolution is now.

Alan J. McCormack, *editor*