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ABSTRACT

Both teachers and students alike acknowledge that genetics and genetics problem-solving are extremely difficult to learn and to teach. Therefore, a number of recommendations for teaching college genetics are offered. Although few of these ideas have as yet been tested in controlled experiments, they are supported by research and experience and may therefore be of some value. They include: (1) 17 recommendations which are not content-specific but relate more to teaching techniques; (2) recommendations for teaching genetics, focusing on those related to elucidating the relationships between meiosis and genetics, careful use of genetic terms, inclusion of probability, emphasis on the problem-solving process, and the importance of practice; and (3) specific recommendations from personal experience. The latter includes providing as many hands-on activities as possible, relating discussions to real world phenomena with which students are familiar, and modeling the problem-solving process and demonstration of problems that are solved. (JN)

Classroom-tested Recommendations for Teaching Problem Solving Within a Traditional College Course: Genetics

by

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Classroom-tested Recommendations for Teaching Problem Solving Within a Traditional College Course: Genetics

Both teachers and stude like acknowledge that genetics and genetics problem solving are extremely ficult--both to learn and to teach. As both a genetics instructor and problem solving researcher, I have been interested both in understanding this difficulty and in providing some practical solutions to the instructional questions. Based on my research, the research of others, and my seven years of experience teaching high school, university, and graduate school students, I would like to present a number of recommendations for teaching college genetics. Although few of these ideas have as yet been tested in controlled experiments, they are supported by research and experience and may therefore be of some value.

I. Recommendations which are not content-specific

Various authors have made a number of proposals which apply to teaching in any field so as to enhance problem solving. Perhaps the best single compilation of these is from Fisher and Lipson (1983 and undated). The follow. g is an adapted version of their recommendations.

1) Create safe, supportive, and intellectually challenging environments for learning.
2) Encourage students to make their implicit beliefs explicit and help them to formulate predictions on the basis of their belief systems. Then provide opportunity for the students to test their own predictions and thus discover the inadequacies of these beliefs. Encourage this conscious examination of mental mechanisms.

3) Make your own implicit knowledge explicit and available to students. [As teachers, so much of our procedural thought processes have become tacit that we are basically unaware of the extensive automatic processing that goes on in our minds. In order to help students learn these processes, we must identify them and make them explicit in our instruction.]

4) Present an alternative way of thinking and encourage students to test your mental model. Once students have realized the inadequacies of their models, the teacher must provide an alternative model which the students can test.

5) Challenge students repeatedly, providing opportunities for them to test their mental constructs by answering questions, solving problems, or performing in other ways.

6) Provide opportunities for students to practice, practice, practice, with frequent feedback on and discussion of their performance.

7) Design study questions that promote development of problem representations, qualitative judgements about appropriate solution paths, and exploration of the problem space rather than simply finding correct answers.

8) Present problems which help expose common student errors.

9) Include many concrete, familiar, and relevant examples in your instruction.

10) Whenever possible, present new information in the form of a story.

11) Emphasize the value of redundancy and checking. Students must learn to routinely monitor their own performance.

12) Recognize that most or all cognitive errors have multiple causes and, therefore, that multiple instructional strategies are necessary for remediating these errors.

13) Help students develop good metacognitive strategies.

14) Concentrate on promoting deep-level rather than surface-level learning. [One way in which this might be done is through the use of "interactive dialogues in which the novice summarizes, interprets, formulates questions and makes predictions about a topic, with an expert providing judicious assistance and comment, [which] can facilitate development of the novice's mental model of the domain (Fisher, 1983).]

15) Teach in the zone of proximal development, i.e., new information should be clearly related to what the learner already knows.

16) Develop a spiral curriculum so that information is acquired in successive approximations.

17) Involve students in the process of science.

II. General recommendations for teaching genetics

Other authors have proposed a number of suggestions which are more narrowly related to teaching genetics in particular. These suggestions have typically focused on one of five areas: elucidating the relationships between meiosis and genetics, careful use of genetic terms, inclusion of probability, emphasis on the problem-solving process, and the importance of practice.

The importance of the student understanding the relationships between meiosis and the genetic phenomena which result has been recognized for some years now, especially by the University of Wisconsin-Madison group. Both instructors and texts have too often treated the two as distinctly separate topics and have failed to help students see the vital relationships involved. Thomson and Stewart (in press) specifically recommend:

1) emphasizing concepts such as gene, allele and locus in the discussion of meiosis;

2) increasing the number and quality of text diagrams that depict meiosis so as to enhance the understanding of gene, allele, and locus in relation to chromosomes;

3) continuing in the genetics discussion to draw chromosomes with alleles on them;

4) including in the text places where students are expected to draw alternate arrangements of alleles on chromosomes at metaphase I to emphasize the concept of randomness in dihybrid and trihybrid crosses.

A second group of suggestions centers around the careful use of genetic terms so as to avoid student confusion. A recent study, in fact, identified improper use of genetic terms in the three most widely used American high school biology texts (Cho, Kahle, and Nordland, undated). In this regard, Thomson and Stewart (in press) recommend:

1) using the concepts of gene and allele, trait and form of a trait consistently so that one concept, such as gene, did not take on the meanings of trait and/or allele;

2) tying the use of empirical concepts like trait and form to their theoretical equivalents; trait with gene and form with allele;

3) reducing the details of meiosis vocabulary (e.g., eliminating concepts such as centrosome, spindle fibers and asters) so that all vocabulary was related to the replication or division of chromosomes; eliminating the term chromatid, using instead the term duplicated chromosome.

Third, both Judith Kinnear (1983) and I have suggested that probability issues involved in genetics should be directly addressed and not avoided, as many instructors do. Avoiding probability appears to encourage student misconceptions about the deterministic nature of genetic ratios. Also, other research (Smith, 1983) suggests that genetics problems do not typically require formal operational skills in dealing with probability. Many instructors find it difficult to teach genetics problem solving using probability, finding it easier to encourage a more algorithmic approach to the problem. This however, circumvents our most critical instructional goals--in-depth understanding of the subject and the enhancement of problem-solving skills--in favor of "getting the right answer."

Similarly, Thomson and Stewart (undated) recognize that more emphasis must be placed on teaching the process of problem solving, breaking the process down into its component parts, and teaching them separately. Stewart has developed a number of problems which ask the student to perform only a single subtask such as setting up the symbol definition key or identifying gamete types. This procedure seems valuable in that it helps the student learn to identify the problem-solving components which are often tacit for the instructor while it allows the instructor to evaluate the student's progress in each component skill.

Most authors seem to agree that the most important thing is probably to provide for plenty of practice. Schuytema (1980), in fact, found that there was a strong positive relationship between the amount of time spent by students in problem-solving laboratories and their problem-solving achievement. Practice time alone accounted for 89% of the variance of problem-solving success. This issue is perhaps one of the most important and time consuming for the classroom teacher to address because the selection of the problems which the students will practice solving can be a large task. We have all too often simply assigned "all the problems at the end of the chapter" and found this to be a grossly inappropriate assignment either in length, type of problem, or level of complexity. In addition, textbook problems usually are not designed with the recent problem-solving research in mind and thus do not make the best use of student practice time.

Two recent instructional techniques deserve attention in this regard. The first is the use of process-oriented, subgoal directed problems designed by Stewart and discussed previously. The second is a course developed by Robert Allen and his coworkers which is designed to "transmit information efficiently and allow maximum student practice in applying this information (Moll and Allen, 1982). Class time is typically spent viewing a short video tape followed by discussion. The video presentation format "provides realistic observations of demonstrations, experiments, and simulation." Emphasis is placed on solving out-of-class exercises and problems. These problems are written in the multiple choice format and students are required to write out a full justification for accepting or rejecting each choice. While the multiple choice/justification format is unusual, Statkeiwicz and Allen (1983) identify its several advantages:

1) Carefully constructed choices can force students to employ more subtle reasoning and can thus provide more sophisticated practice.
2) The different choices can force students to examine different points of view on a problem.
3) Different choices can focus on several common misunderstandings.
4) Providing choices can substitute for teacher guidance and increase the effectiveness of the problems as out-of-class exercises.

In addition, out-of-class exercises themselves permit students to extend practice time and thus spend the time necessary for reflection on their justifications. A large number of such problems has been developed in such areas as ecology, diffusion, respiration, photosynthesis, and the cell as well as genetics and is commercially available (Donovan & Allen, 1983).

When this course was implemented as an introductory college biology course, students' analytical skills were observed to show significant improvement and this improvement was shown to be significantly correlated to student performance on the practice problems (Statkeiwicz & Allen, 1983). These skills were also observed to be transferable to unfamiliar and novel problems requiring new applications of their knowledge.

III Specific Recommendations from personal experience

Several other suggestions arise from personal experience.

1) Make it clear to students that, by its very nature, genetics is a qualitatively different type of subject than many of their other classes. Genetics requires problem solving and cannot be approached like many other classes as principally a task of memorization.

2) Wherever possible, relate the discussion to real world phenomena with which the students are familiar. For example, I often introduce the whole idea of heredity by relating the personal story of a relative who has a rare genetic disease. Similarly, when discussing the probabilistic nature of genetic ratios and the effect of small sample size, I always relate the question to male/female ratios in small families which the students appear to have a clear grasp of.

3) Provide as many hands-on activities as possible. As time permits, I include several coin toss exercises, fruit fly experiments, karyotyping, pop-bead modeling of chromosome behavior, blood typing,

personal pedigrees, and other human phenotyping (PTC tasting, red-green colorblindness, etc.) Providing this kind of activity is well documented as appropriate for preformal operational students (Kamii, 1978).

4) Whenever you discuss solving problems, put especial emphasis on the process. For example, when students first begin to solve problems, I suggest that they follow a specified series of procedural steps which approximate the subgoals identified by Thomson and Stewart (undated) and Smith (1983). Students may at first use these procedures algorithmically, but this does ensure some initial success.

5) Encourage students to think about their own thinking and problem solving strategies as they solve problems; to think about what they are doing and why at each step in a problem solution.

6) Learn to view your role as that of a "thinking coach" instead of as an information disseminator. This will involve
   a) relating to the student as a total person;
   b) supporting the development of a positive concept;
   c) providing a supportive atmosphere in which the student feels comfortable to attempt new things, to fail and/or succeed;
   d) analyzing student performance and providing constructive feedback;
   e) encouraging accurate self assessment;
   f) encouraging the student to take personal ownership of the activity (thinking) as a personal goal.

7) Before you introduce the Punnett square, show that the various types of offspring are produced by the combination of each type of egg with every type of sperm. (This may be done with the "crisscrossed lines"

method.) Introduce the Punnett square as a simple way to model this process so as to identify all possible combinations and not miss any possibilities.

8) Model the problem-solving process as you solve demonstrations problems. As you model:

a) "think aloud", i.e., verbalize as much as possible all of the thought processes which you go through. This will take special effort and forethought to identify many of the processes which are tacit for you. Try solving a problem in class that you have not practiced beforehand.

b) encourage students to draw an explicit symbol definition key. Students often see this only as an instructional device which they do not need.

c) encourage students to explicitly draw the possible gametes from each parent. Many students see this as unnecessary and omit this step. Many experts often omit this step as well since this step is automatic for them. When novices do not omit this step, however, they are less prone to make errors.

d) In order to enhance understanding of the relationships of genetics to meiotic events, frequently draw chromosomes with the appropriate alleles on them in metaphase I and show how the arrangement leads to the gametes to be drawn in the Punnett square.

e) Present problems which emphasize typical student misconceptions or errors. These include problems such as pedigrees which have small numbers of offspring which help the student to see the difference between deterministic and probabilistic genetic ratios.

f) Point out typical student errors. As I solve the problems, I frequently ask for feedback from students as to whether or not the last step executed is correct. Often I purposely make a typical student error at this point so that we can discuss why it is incorrect. These errors include using two different letters for a pair of alleles, omitting the X and Y chromosomes in sex linkage problems, drawing only one allele (letter) in each gamete in a dihybrid cross, and putting some gametes from both parents on the same side of the Punnett square. (I encourage students to draw a circle around the female gametes to symbolize "egg" and a circle with a tail to symbolize "sperm" so that they have a visual strategy for avoiding this error.)

g) Discourage the algorithmic use of the Punnett square. This can be done once the students are adept with simple problems by demonstrating problems which require some modification of the algorithm. For example, you might include a testcross to show that all ratios are not 3:1 and then a cross of a dominant homozygote with a heterozygote or even two homozygotes. In these latter two cases, encourage students to only draw "all the possible different gametes"--terminology you have already used regularly. Students who can see that a 4X4 Punnett square is not needed in this case are demonstrating a deeper level of understanding than an algorithmic use of the Punnett.

h) Encourage students to make qualitative checks of their work. For example, if a student solving a dihybrid cross obtains a genotype containing only 2 "letters" (i.e., the individual has no letters for the second trait), this should be recognized qualitatively as incorrect. Too often students work through a problem, obtain an "answer", and quit even though the "answer" is obviously impossible. This is especially true with the dihybrid and sex linkage problems.

i) Encourage categorization. After students have worked on a few different types of problems, encourage them to begin each problem by asking "What type of problem is this?"--simple dominance, incomplete dominance, multiple allele, dihybrid, etc. This encourages the student to think about the process of problem solving and to plan the solution path to be taken.

IV Recommendations for further research

The time has clearly arrived for testing the effectiveness of these recommendations in carefully designed and controlled classroom studies. Anyone who has access to appropriate student samples and is interested in pursuing this issue should contact me directly.

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