Making Quantitative Genetics Relevant: Effectiveness of a Laboratory Investigation that Links Scientific Research, Commercial Applications, and Legal Issues

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ABSTRACT: As students apply their knowledge of scientific concepts and of science as a method of inquiry, learning becomes relevant. This laboratory exercise is designed to foster students' understanding of the genetics of quantitative traits and of the nature of science as a method of inquiry by engaging them in a real-world business scenario. During the investigation, students explore the question of whether the patent rights of a commercial producer of sunflower seeds have been infringed upon by a rival company. Students work as a research team to explore the question, making observations, collecting and analyzing data utilizing statistical tools, and ultimately drawing conclusions regarding possible patent violations. Student-evaluations of the exercise indicate that they perceive that the activity fostered their understanding of genetic principles and of important aspects of scientific inquiry and made the content relevant by linking it to real-world issues.

KEYWORDS: genetics, relevant content, statistics, t-test, patent rights, quantitative traits

INTRODUCTION

The use of real-world, student-relevant activities, assignments and curricula that invoke students' critical thinking skills is recognized as a powerful approach to engage students and promote meaningful learning (Biack and Biack, 1999; Chin and Brown, 2000; Crow, 1989; van Rooyen & de Beer, 1994). Such activities allow students to apply their understanding of scientific principles and science as a method of inquiry. These applications are vital because they foster the formation of informed decisions, and make learning meaningful (Chang, 2000; Sojka, 1992; Demers, 2003). The connections between scientific research and commercial ventures that have associated legal issues provide a rich area from which to develop activities that are relevant to students' lives and promote critical thinking.

An objective of the genetics course at Middle Tennessee State University is to foster student understanding of genetic principles and scientific methods while encouraging students to critically apply their knowledge to answer relevant personal and societal questions. This paper describes a laboratory investigation that utilizes a real-world business scenario involving potential patent right infringements with respect to sunflower seeds. The laboratory is designed to:

- promote student understanding of quantitative traits.
- foster student understanding of science as a method of inquiry, including the analysis of data using statistical procedures.
- introduce students to the connections between scientific research and commercial applications, including legal issues associated with the patenting of organisms.

- provide course content that is interesting and relevant to students' everyday lives.

As students investigate questions concerning potential patent right infringements, they utilize the tools and techniques commonly used in scientific decision-making -- characteristics recognized as fundamental to quality science education (American Association for the Advancement of Science, 1993; National Research Council, 1996; National Science Foundation, 1996).

BACKGROUND (PRE-LAB DISCUSSION)

The laboratory exercise is prefaced with a discussion reminding students of the historic events leading to the contemporary understanding of heredity—including the 'Mendelian viewpoint,' which held that all evolutionarily important genetic differences are qualitative and discontinuous, and the 'biometrical viewpoint,' which held that genetic variation is fundamentally quantitative and continuous. The multiple gene hypothesis (polygenic model) of inheritance contributed by H. Nilsson-Ehle, which shows that continuous variation can be explained in Mendelian terms, is also discussed. It is explained that traits that are controlled by polygenes show a continuous variety of phenotypes (as opposed to a few discrete phenotypes), and vary by degree. Hence, their phenotypes can be expressed as a number rather than a descriptive word (e.g. tall or dwarf). It is pointed out that this fact makes it possible to apply statistical methods for comparing two populations with respect to quantitative traits, such as the number of stripes per achene on sunflowers, to determine if differences exist. Additionally, it is noted that in the world of commerce, genetic matters are sometimes intertwined with legal issues, and a trait seemingly as meaningless as the number of stripes on sunflower seeds can be of particular significance.

In addition to the necessary genetic background, students are made aware of the growing commercialization of genetic discoveries. The landmark U.S. Plant Patent Act of 1930 and the 1980 U.S. Supreme Court decision in the case of the Commissioner of Patents and Trademarks v. Chakrabarty are cited as indications of the growing importance of patented varieties of plants, microorganisms, and other life forms. The former cleared the way for commercialization of plant varieties based on application of classical genetic knowledge; whereas, the latter cleared the way for protection of novel genetic varieties of microorganisms created through recombinant DNA technology (http://www.fcgp.org; accessed 9/16/2004). Awareness of the growing importance of proprietary issues in genetics is further emphasized through a simple Web assignment in which students are asked to find current examples of cases involving possible patent right infringement.

DESCRIBING PHENOTYPIC VARIATION

Students are supplied with a data set of ear length in corn (a quantitative trait). The calculations of the mean and standard deviation are reviewed. The phenotypic variation exhibited in the data set is utilized to illustrate the normal distribution and the relationship between sample means and standard deviations. Students are given a small data set to practice calculating variance and standard deviation.

Comparing Two Populations (Student's t-test)

The concept of standard error and its computation are reviewed. It is pointed out that much of the work in science involves the use of samples or subsets of populations and that standard error, the standard deviation of a distribution of sample means, is incredibly useful in scientific research as a means of determining whether populations differ with respect to a parameter of interest (e.g. stripes/achene in sunflowers). Students are asked how likely it is that two successive sample means from a population will be the same. They typically appreciate that it is highly likely that the two means will be different despite the fact that they are drawn from the same population. Students are then asked, "How can we be certain that two means are different enough for us to be suitably confident that they came from different populations?" Student response is utilized to expand the discussion of how statistics are useful to scientists, and that statistical analyses indicate how much difference must exist between two means for them to be deemed 'significantly different' at a given significance level (α-level). Students are reminded that in science the minimum significance level is 0.05 -- that is, differences that are realized with a 5% or less chance of error are deemed 'statistically significant.'

Students are asked to name types of statistical tests with which they are familiar. Chi-square is often listed by students and is used along with others that are mentioned to expand the discussion of different types of statistical tests. If students don't mention 't-tests' it is offered as a statistical test that is particularly useful in determining if differences between two sample means are meaningful. Students are then presented with the formula for calculating the independent samples t-test and the assumptions associated with its use are reviewed. Students are asked, "How can the calculated t statistic be used and what does it mean?" Student responses are utilized to point out that the t-test compares the actual difference between two means in relation to the variation in the data. It is observed that the two-sample t-test can be used to study quantitative traits in genetics to determine if two samples are drawn from the same phenotypic (and genetic) population.

Students are asked if they are aware of business applications in which determining if organisms represent a single or two different populations would be important. Student responses are used to expand the discussion to include legal issues surrounding the patenting of organisms and patent right infringement. Discussion of the significant research and development costs to companies in the production of seeds of proper genetic stock, and the desire to protect their discoveries through the patent rights, sets the stage for the laboratory exercise.

THE EXERCISE

The Sunflower Seed Scenario

Students are asked to consider the following scenario:

Company A has developed and obtained patent rights for a variety of sunflower (variety VTX1) that is characterized by possessing a specified number of stripes per achene. The company believes that a competing company (Company B) has infringed on their patent rights by marketing the same variety of sunflower under a different name (variety B100).

Students, working in research teams of two individuals, are charged with using their understanding of quantitative traits and statistical procedures to determine if there is a patent right infringement. Research teams are instructed to:

- obtain 15 seeds from each company's stock.
- count the number of white stripes that run at least half the length of each achene (ignore differences in stripe width -- a stripe is a stripe).
- count all the way around the achene. If a stripe wraps around the edge, make sure you only count it once.
- exclude seeds that are immature and lack stripes or have been mechanically damaged by the harvesting process.

As students complete the exercise, they are asked to calculate the mean and standard error for each sample. As an assignment for the next lab meeting, students are asked to utilize the data they collected to form a statistical analysis (t-test) to determine if the data support the null hypothesis, the two samples are from the same population and Company B has infringed on the patent rights of Company A, or the alternative hypothesis that the seeds represent two genetically distinct populations. Additionally, students are given data from seeds of a third company, Company C. Company C is marketing a variety of seeds (variety MSR2) suspected of representing an infringement of Company A's patent rights. Students are asked to analyze these data in a similar fashion to determine if Company C may have infringed on the patent rights of Company A. The data supplied for Company C's seeds are: 4, 7, 6, 8, 3, 4, 5, 6, 3, 3, 5, 8, 3, 4, 5.

RESULTS

At the beginning of the next lab meeting, student research teams present their observed data, statistical analyses and conclusions with respect to potential patent right infringements. Most research teams find no statistically significant difference between the two observed samples and conclude that the data provide initial support that Company B may have infringed on the patent rights of Company A, and that seed varieties VXT1and B100 are genetically the same with respect to the number of stripes/achene (Table 1). Further, when students analyze the data from Company C's variety, they typically do find a statistical difference between the varieties and conclude that the varieties represent two different populations, indicating that Company C likely has not infringed on the patent rights of Company A (Table 2).

Table 1*. Two sample t-test for number of stripes per achene in sunflower varieties.*

Statistic	Variety of Sunflower	
	VXT1	B100
n	15	15
$\bar{x}$	8.46	8.4
s	3.86	2.98
SE	0.99	0.79
s_d	1.27	
t	0.047	

Table 2. *Two sample t-test for number of stripes per achene in sunflower varieties.*

Statistic	Variety of Sunflower	
	VXT1	MSR2
n	15	15
$\bar{x}$	8.46	4.93
s	3.86	1.69
SE	0.99	0.44
s_d	1.08	
t	3.29	

The results of research team presentations are used to expand the discussion to include issues of sample size and the power of statistical tests. Additional data from Company C's variety are provided (30 more seeds) and the data of Company A's seeds from three research teams are combined. A t-test is calculated using the increased sample size to demonstrate that differences can be declared at lower significance levels when samples are larger. The discussion may be expanded further to include the range of calculated power of a given t-test and the sample size required to achieve a stated level of power.

INSTRUCTOR NOTES

Before students obtain their samples, the seeds are inspected and chaff/debris, as well as badly abraded and immature seeds, are removed. Sunflower seeds from a common source are acquired from a local seed store and divided into the two varieties -- VXT1 and B100. Thus, students typically find that the two populations being compared are not different, leading them to conclude that Company B may have actually violated the patent rights of Company A. The supplied data for Company C are discernibly different from that of Company A, leading students to conclude that there is no patent right infringement in this case. As mentioned above, this exercise is often combined with an assignment in which students search the Internet for contemporary cases of patent right infringement, or possible infringement. This assignment helps to foster student interest. When combined with prior background pertaining to the nature of quantitative inheritance and at least some familiarity with the concept of statistical inference, students are prepared to successfully complete the exercise. Potential users of this exercise, or a similar exercise, should note that the exercise can be adapted to fit the background of a particular student population (typically, our students are junior level biology majors). The exercise may, for example, be successfully completed without consideration of the effect of increased sample size on the conclusions reached or mention of the concept of 'power.'

STUDENT EVALUATION

The rationale for developing this exercise was to involve students in an investigation that allowed them to apply their understanding of genetic principles and of science as a method of inquiry in a real-world context in such a way to make the content relevant and to invoke their critical thinking skills. The educational objectives of the assignment center on increasing students' understanding of quantitative traits and of science as a method of inquiry, as well as fostering their appreciation of the connections between science and industry. Additional objectives include making the content relevant and interesting to students while engaging their critical thinking skills. To assess student perceptions of the effectiveness of the exercise, students in four lab sections were administered a seven-item survey after they turned in their assignment (Table 3). The survey, which was filled out anonymously, asked students to rate each aspect of the exercise on a numerical scale according to the degree with which they agree or disagree with each statement.

Mean scores for all items were above 3.7 on the five-point scale (Table 3). The majority of students indicated a degree of agreement for each item. Overall, the scores suggest that students perceived that the activity achieved its educational objectives and fostered their understanding of genetic principles and of important aspects of scientific inquiry while making the content relevant and meaningful by linking it to the real-world issue of patent right infringement. It is interesting that the mean scores were somewhat lower and the amount of deviation was greatest for the two questions: 1) Have a greater understanding of legal issues associated with the patenting of organisms, and 2) The laboratory activity was interesting to me. This might suggest a difference in the background of the students and thus their appreciation for these areas, or that changes in the presentation of the materials should be made to greater emphasize these areas.

Table 3. ***Students' evaluation of effectiveness of the laboratory exercise.***

QUESTION: As a result of the laboratory exercise I believe that I now:	Score	SD
have a greater understanding of quantitative traits. Disagree 1 2 3 4 5 Agree	3.84	0.82
have a greater understanding of the role of statistics in science. Disagree 1 2 3 4 5 Agree	4.22	0.84
have a greater appreciation of the connections between science and industry. Disagree 1 2 3 4 5 Agree	3.74	0.99
have a greater understanding of legal issues associated with the patenting of organisms. Disagree 1 2 3 4 5 Agree	3.80	1.10
am more comfortable interpreting the data (statistical analysis) in scientific reports. Disagree 1 2 3 4 5 Agree	3.89	0.95
QUESTION: The laboratory activity:		
was interesting to me. Disagree 1 2 3 4 5 Agree	3.80	1.14
made the content (quantitative traits) relevant. Disagree 1 2 3 4 5 Agree	4.16	0.78

Note: n = 76

CONCLUSIONS

As students apply their understanding of scientific principles and science as a method of inquiry to real-world situations, their learning becomes connected to their experiences and is thus more meaningful. Often students lack an appreciation for the connections between science and the broader realms of business, society, and philosophy. This laboratory investigation is designed to foster student understanding of genetic principles and of science as a method of inquiry by engaging them in a business application involving potential patent right infringements. It gives them a real-world context for the biological and scientific content. As students conduct the exercise they work as part of a research team, make observations, collect and analyze data utilizing statistical tools, and draw conclusions. Initial feedback suggests that students perceive that the laboratory exercise provides them with an increased understanding of the genetics of quantitative traits and science as a method of inquiry while making the content relevant and interesting. Further, the activity serves as a concrete referent of science as a method of inquiry and of the connections between science and business upon which the course can be further developed.

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